NIMBUS-B SOLAR-CONVERSION POWER SUPPLY SUBSYSTEM

QUARTERLY TECHNICAL REPORT NO. 4

JUNE 1966 THROUGH AUGUST 1966

Contract No. NAS5-9668

Prepared by

Astro-Electronics Division
Defense Electronic Products
Radio Corporation of America
Princeton, New Jersey

for

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland

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AED R-3076

Issued: October 17, 1966

PREFACE

This is the fourth in a series of quarterly technical reports on the development of the Solar-Conversion Power Supply Subsystem for the Nimbus-B Meteorological Satellite. This project is being conducted by the Astro-Electronics Division (hereafter called AED) of RCA for the National Aeronautics and Space Administration (NASA) under Contract No. NAS5-9668. The present report covers the work accomplished during the period from June through August 1966.

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SECTION I
SYSTEMS CONSIDERATIONS

A. INTRODUCTION

During the period of June, July, and August 1966, the systems engineering effort included a limited performance investigation of power subsystem operation with six storage modules (battery modules). An investigation was made to determine the compatibility of the existing battery discharge current telemetry range with system requirements. A procedure for power subsystem turn-on and turn-off was recommended. Studies were made of the effect of radiation from the Radioisotope Thermoelectric Generator (RTG) on solar-array degradation.

The functional block diagram of the Nimbus-B power subsystem was revised, as shown in Figure 1, to reflect changes incorporated in this quarterly period.

B. POWER SUBSYSTEM OPERATION WITH SIX STORAGE MODULES

The purpose of this investigation is to determine the performance of the power subsystem for one year in orbit with six storage modules. Previous subsystem capability investigations were conducted for a 7-battery system and were reported in Section II of Quarterly Technical Report No. 2, March 31, 1966.

To date, the 6-module system work has been performed for a nominal-case system at beginning-of-life (BOL), and at 6, 9, and 12 months with battery temperatures of +25°C and +35°C. The nominal-case system design factors and characteristics are described in the above-referenced report. The Nimbus-B energy balance computer program was run for each condition considered in this investigation. The load profile for each run was the maximum average regulated bus power that the 7-module system could support and still remain in per-orbit energy balance. As the 6-module system could not supply this load and still obtain the required recharge for the batteries, an adjusted value was calculated which would permit energy balance.

The results of the 6-storage-module system computer runs are summarized in Table 1, which shows the 7-storage-module system maximum load, the 6-module system maximum load, battery depth-of-discharge, minimum unregulated bus voltage during the orbit, and ampere-minutes into the shunt dissipator for each time in life and battery temperature considered.

1. Load Power Capability

The average load column in Table 1 describes the -24.5-volt power the solar conversion power subsystem can supply during an entire orbit. In addition, a 164-watt transmitter load is superimposed on top of this average power for a period of 7.5 minutes during each orbit. Power availability from the RTG subsystem may be added to the values tabulated to describe the full spacecraft load capability. The slight power loss (about 3 watts) with a 6-module system compared with a 7-module system is due to the increased amount of energy removed from the batteries at a lower voltage during discharge periods and the resulting extra recharge required from the array during satellite day.

2. Charge-to-Discharge Ratios

The load values represent the maximum power that can be supplied and still replace the energy removed from the batteries with an excess of 25 percent at a temperature of +25°C and 35 percent at +35°C. These charge-to-discharge ratios (C/D) of 1.25 and 1.35 represent the RCA recommendation to ensure proper battery operation for one year of orbital life.

3. Depth of Discharge

The values of depth of discharge (DOD) in Table 1 represent percent of capacity removed during the nighttime discharge period for the corresponding 6-module system regulated bus load at beginning of life and 25°C. The DOD encountered during one year, with the +25°C battery temperature, ranges from a low of 14.3 percent for the maximum orbital load with the RTG contributing 50 watts at beginning of life, to a maximum of 17.8 percent, which represents the maximum load (205 watts) for which energy balance can be maintained. It is the opinion of RCA that these discharges are not excessive if battery temperature is maintained at +25°C or lower.

At battery temperatures of +35°C, the power subsystem can support a DOD as great as 17.5 percent at beginning of life (195-watt load on regulated bus) and still replace the removed energy by a ratio of 1.35. However, RCA strongly recommends that the batteries be discharged no more than 15 percent, on an average basis, to ensure one year of operation at +35°C. The load that would limit the DOD to 15 percent is about 165 watts, which, with 50 watts from the RTG subsystem, would permit operation of the full spacecraft load* for 9 months in orbit, and a load approximately 7 watts less than full load to the end of one year.

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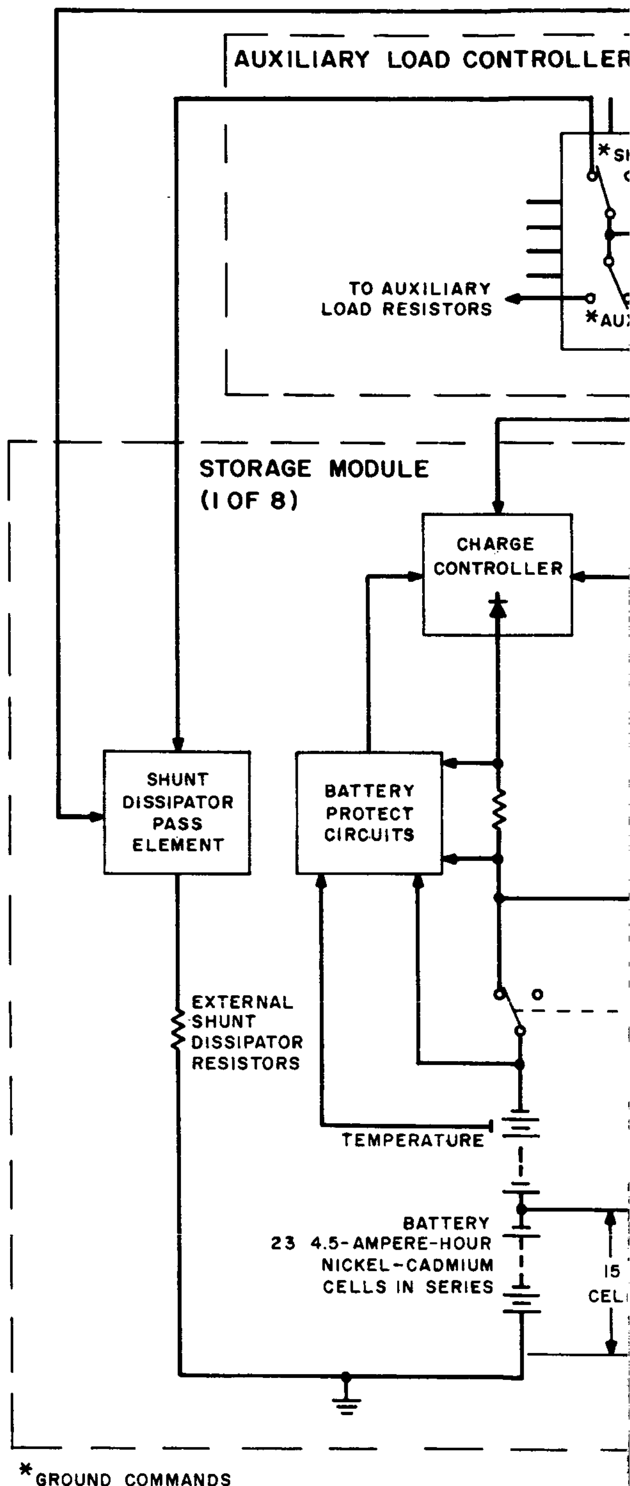
*The maximum orbital load profile is obtained from Figure 4.1, General Electric Co. PIR 4185-073, dated 2/17/66 "Solar Power Subsystem Interface Agreement."


AUXILIARY LOAD CONTROLLER
TO AUXILIARY LOAD RESISTORS
STORAGE MODULE (1 OF 8)
CHARGE CONTROLLER
SHUNT DISSIPATOR PASS ELEMENT
BATTERY PROTECT CIRCUITS
EXTERNAL SHUNT DISSIPATOR RESISTORS
TEMPERATURE
BATTERY 23 4.5-AMPERE-HOUR NICKEL-CADMIUM CELLS IN SERIES
*GROUND COMMANDS

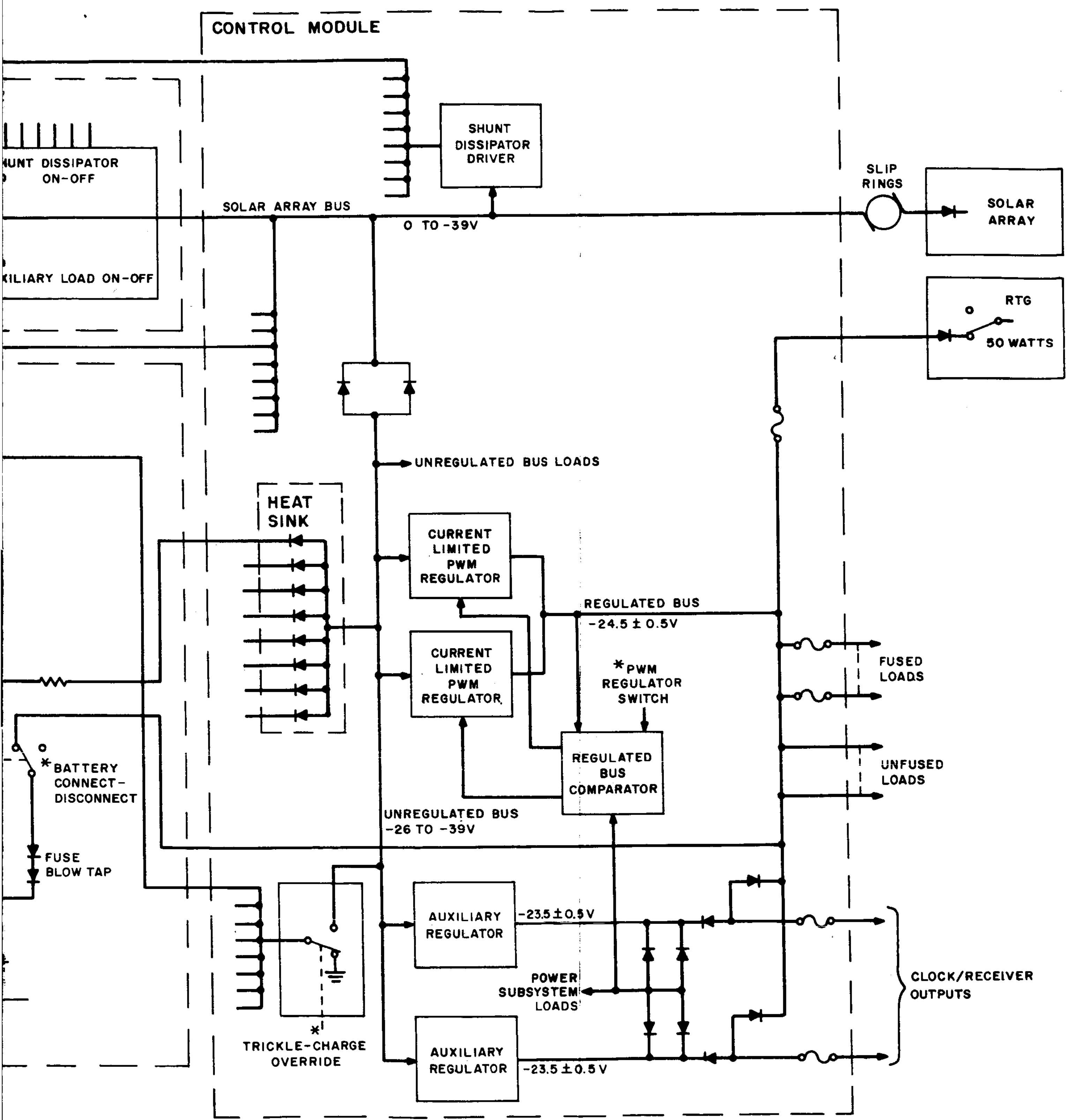


Figure 1. Nimbus-B Solar Conversion Power Supply Subsystem, Block Diagram

TABLE 1. RESULTS OF NIMBUS - B POWER SUBSYSTEM INVESTIGATION, FOR NOMINAL CASE, WITH SIX STORAGE MODULES

Batt. Temp. (°C)	Time in Orbit (months)	Average Load* (watts)		DOD † (percent)	Miminum Unregulated Bus Voltage (volts)	Shunt Dissipation (Amp-Min)
		Seven Storage Modules	Six Storage Modules			
25	BOL**	Max. Orb Load W/RTG		14.3	28.0	70.0
25	BOL	208	205	17.8	27.9	3.1
25	6	182	179	16.3	27.4	0
25	9	174	171	15.8	26.7	0
25	12	171	166	15.1	26.6	0
35	BOL	Max. Orb Load W/RTG		15.0	27.2	34.9
35	BOL	205	195	17.5	27.1	0
35	6	175	172	15.7	27.0	0
35	9	168	165	15.6	26.1	0
35	12	163	158	14.7	25.9	0

*Transmitter load of 164 watts for 7.5 minutes in addition to constant average load is included.

**Beginning of life.

†Depth of discharge (DOD) is defined as percent of initial battery capacity at 25°C.

4. Minimum Unregulated Bus Voltage

A minimum value of -26.0 volts on the unregulated bus (input to main PWM regulators) is recommended in order to ensure good regulation of the -24.5-volt bus. This minimum value is exceeded for all conditions investigated except at one year in orbit at a battery temperature of +35°C with a 158-watt load, at which time the unregulated bus voltage reaches a minimum of -25.9 volts. No harmful effects are anticipated for this condition; voltage regulation will be maintained within the required tolerance (-24.5 ± 0.5 volt).

5. Conclusions

Based on the Crane cycling data for the GE NiCd cells, which form the basis for the Nimbus B battery performance predictions, and the results of the energy balance computer investigations, a nominal-case Nimbus-B power subsystem with six storage modules can support a one-year mission with only a slightly reduced capability compared to a 7-storage module system (approximately 3 watts less average power on the regulated bus). At battery temperatures approaching the maximum expected limit of +35°C, the depth of discharge should not be permitted to exceed about 15 percent on a long-term average basis in order to ensure cycling capability for one year. With the RTG contributing 50 watts to the regulated bus, it is expected that the full spacecraft load profile can be supplied for one year with battery temperatures between +15°C and +25°C, and for 9 months with battery temperatures up to +35°C. A slightly reduced capability would result for the period between 9 months and one year at the higher temperature.

This investigation has been confined to energy-balance considerations only, for a 6-battery nominal-case system. Investigation of a 6-battery worst-case system and effects on other aspects of system performance such as shunt dissipator capability with only six storage modules, magnitude of individual battery discharge current, and system capability in the event of failure of any of the six storage modules has not been performed.

C. BATTERY DISCHARGE CURRENT TELEMETRY RANGE

The present contract under which the Nimbus-B power subsystem has been designed and for which hardware is being fabricated specifies a system containing eight storage modules. The system shall be capable of normal operation with only seven of the eight storage modules during the mission. During all system tests, eight storage modules will be operating.

The maximum regulated bus load for which system performance has been investigated was specified to RCA by NASA, and is described in GE PIR 4185-073

"Solar Power Subsystem, Interface Agreement", dated February 17, 1966. This maximum load is 217 watts plus a 164-watt interrogation transmitter load, a total of 381 watts from the regulated bus at -24.5 volts. Assuming that the RTG does not contribute power, the load must be supplied entirely from the PWM regulator. With the batteries as the source for all the power, the control module efficiency at this load value is 92 percent. An additional shunt loss of about 13 watts occurs in the seven storage modules; resulting in a total battery discharge load of 428 watts (13 + 381/0.92). The unregulated bus voltage for a battery at a temperature of +35°C near beginning of life and at a 15-percent depth of discharge is estimated at 27.3 volts. The total battery current is determined to be 15.7 amperes (428 watts/27.3 volts). The resulting current to each battery with seven storage modules operating is 2.24 amperes.

During system testing (eight storage modules operating), a 20-ampere regulated bus load (maximum PWM regulator capability) results in a power of 490 watts being supplied by the regulator at an efficiency of 92 percent. The total battery load, including shunt losses, is 542 watts. The unregulated bus voltage for a system with batteries at a temperature of +25°C and 15-percent depth of discharge is 28.0 volts, resulting in a total battery discharge current of 19.34 amperes (542 watts/28.0 volts). The discharge current from each battery for this maximum test load with an 8-storage-module system is 2.42 amperes.

The present circuit for discharge-current telemetry has a telemetry output voltage that ranges from -0.5 to -6.4 volts for a battery discharge current of 0 to 2.6 amperes. As shown by the foregoing analysis, this current range is more than adequate for the operation of a power subsystem containing 7 or 8 storage modules.

A discharge current from each battery of 2.6 amperes (maximum telemetry value) corresponds to a regulated bus load of 510 watts with an 8-storage-module system, 450 watts with a 7-storage-module system and 380 watts with a 6-module system. A discharged battery at 28 volts was assumed for these calculations.

D. POWER SUBSYSTEM TURN-ON AND TURN-OFF PROCEDURE

The following recommendations are made by RCA for the turn-on and turn-off procedures for the Nimbus-B power subsystem. The procedures described will afford the least possibility of damage to power subsystem components (batteries, battery discharge diodes, connectors and regulator input filter capacitors) during the many occasions when the system is turned on and off during testing.

1. Connectors

Battery power, solar-array or solar-array-simulator power, or load power connectors should not be removed or replaced when the power subsystem is energized. Arcing at the connector pins could occur, resulting in increased resistance at the connection or more severe damage.

2. Turn-On Procedure

The current-limited (13- to 14-ampere) solar array simulator should be switched on and adjusted slowly from 0 to -33 volts before any batteries are commanded on. Increasing the voltage slowly allows the operator to observe any excessive current condition which may exist in the subsystem. As the simulator voltage approaches -25 volts, the energized auxiliary regulators will turn on the PWM regulator, at which time a high-current surge may be observed (charging the regulated-bus filter capacitors). When the solar-array simulator voltage reaches approximately -33 volts, the batteries may be connected to the unregulated bus through their respective relays with the Battery On ground command.

Battery power should not be used to energize the regulators because of the possibility of arcing at the battery relay contacts and excessive current surges through the battery discharge diodes.

The proper procedure for power subsystem turn-on is described in the Control Module Performance Specification.

3. Turn-Off Procedure

The solar array simulator should be adjusted to approximately -33 volts before the batteries are disconnected from the unregulated bus by the use of the Battery Off ground commands. After disconnecting the batteries, the solar-array simulator output voltage should be adjusted to 0 volts, then switched off. This procedure will eliminate the possibility of arcing at the battery relay contacts and will prevent unequal battery discharging as the batteries are individually disconnected.

The shunt dissipators must be operative during the turn-off procedure to prevent excessive unregulated bus voltage, which might occur with a light load on the regulated bus after the batteries have been disconnected.

E. RTG RADIATION EFFECTS ON SOLAR ARRAY

The following discussion results from an investigation by RCA concerning the potential radiation damage to the Nimbus B solar array, caused by particle irradiation from the SNAP 19 RTG.

The Hittman Associates Report HIT-190* gives 2.1×10^{10} as the integrated value of the neutron flux at the mid-point of the solar array after a 6-month test period and one year in orbit. Although the neutron flux at any particular moment may be quite different at different points on the solar array (inverse square law) the average flux over the mission period because of rotation of the paddles should not be far different from the mid-point value. The damage producing capability of this neutron flux can be expressed in terms of the equivalent effect produced by 1 mega-electron-volt (MeV) electrons called DENI's for Damage-Equivalent Normally Incident 1 MeV Electrons per square centimeter. Recent experiments** indicate that neutrons are about 2000 times more effective in producing bulk damage in solar cells than 1 MeV electrons. On this basis the average dose from neutrons affecting the solar array will be 4.2×10^{13} DENI's. A considerably lower value will result if this calculation is based on the data in HIT-190 which indicates that the neutron-to-1-MeV electron conversion factor is only about 200.

Under either condition, the damage effect from neutrons will be small compared with the anticipated effect of high-energy protons and electrons in the Van Allen belt. The one year integrated does from space radiation will be 26.0×10^{13} DENI's based on the calculating procedures normally used at RCA. That this value is somewhat higher than the value of 18.7×10^{13} listed in report HIT-190 is apprently due to several differences in the assumptions with respect to the radiation environment and the conversion factors used in obtaining the total integrated dose in DENI's. In converting proton flux to DENI's, for example, a factor of about 2500 was used in the RCA calculations based on published data from BTL experiments. In report HIT-190 the factor used was about 200, roughly the same as that used to convert neutron flux to the equivalent number of 1 MeV electrons.

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* "Preliminary Assessment of the Effects of Nuclear Radiation on the Nimbus B Spacecraft," November 1965.

** Previous estimates of this factor have ranged from 200 to 5000. The value of 2000 used in this report is based primarily on the results of recent RCA experiments involving the exposure of typical solar cells to radiation from the nuclear reactor at Industrial Research Laboratories, Plainsboro, N. J. The resulting data are in excellent agreement with similar data published by J. Belinski in the July 1963 IEEE Transactions on Nuclear Science.

A difference is also apparent in the factors used to convert the gamma radiation from the RTG to the equivalent dose in DENI's. However, the fraction of the total dose from this source will still be insignificant even if calculated on the basis of the somewhat higher conversion factor from report HIT-190.

F. STATUS OF PERFORMANCE SPECIFICATIONS

Preliminary versions of the power subsystem performance specification (NB-SP-070, Rev. B), control module performance specification (NB-SP-094), and storage module performance specification (NB-SP-120) were completed and forwarded to NASA-GSFC for review during the fourth quarter. These specifications are currently being revised and updated to accommodate changes in power subsystem design which have been incorporated since the writing of the specifications.

SECTION II
CONTROL MODULE

A. GENERAL STATUS

During the fourth quarterly period, the engineering model of the control module (electronics module) was modified and completed. Breadboard tests were performed to determine the electrical compatibility of the RTG converters with the power subsystem. Two fuse boards and two printed-circuitboards were redesigned, and fuses were selected. The Power Subsystem Connection List was issued.

B. CIRCUIT MODIFICATIONS

1. Trickle-Charge Override Telemetry

Telemetry for verification of the trickle-charge override command has been incorporated into the control module. The telemetry addition is shown in Figure 2. It consists of two resistors, R1 and R2, and a capacitor, C1.

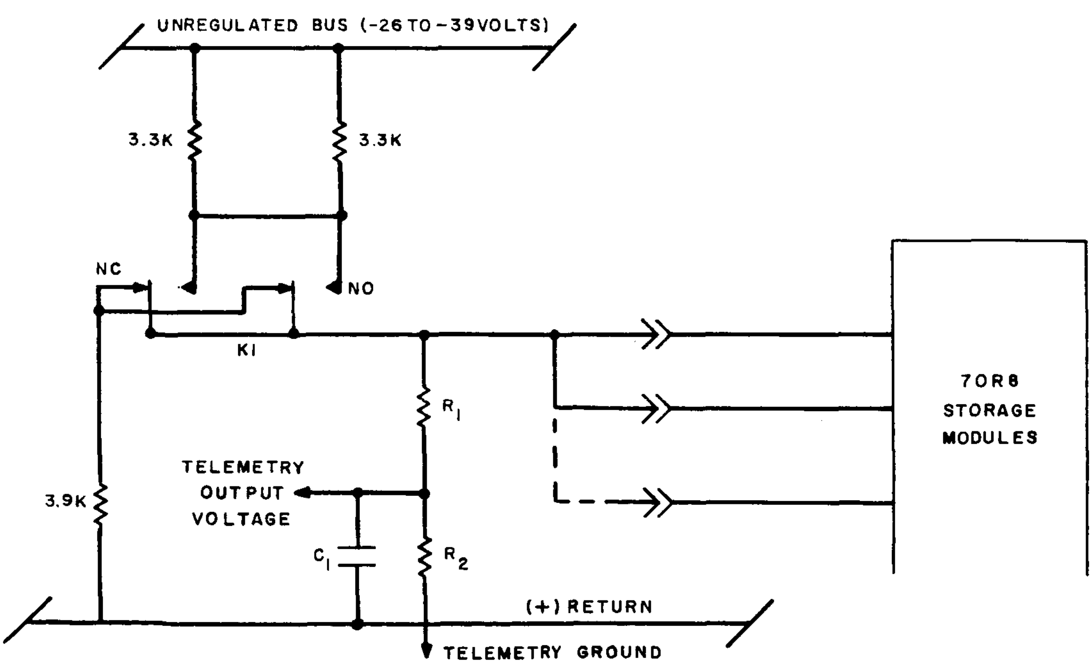


Figure 2. Trickle-Charge Override Command Verification Telemetry Circuit, Schematic Diagram

The output telemetry voltage with the relay in the normally closed (NC) position is 0 volts with an output impedance less than 50 kilohms. Upon the receipt of a Trickle Charge Override command, the relay contacts transfer to the normally open (NO) position. The output telemetry voltage will indicate between -5 and -10 volts for an unregulated bus voltage. The telemetry will be read out as a digital function, with an output of -5 volts to -10 volts for the ON condition and 0 volts for the OFF condition.

2. Regulated Bus Comparator Ground Command

The ground command signal for switching regulators using the regulated bus comparator (RBC) was changed from -12 volts to -24.5 volts. Accordingly, the ground command input circuit was changed to be compatible with the new ground command signal. This modification entailed changing the values of two resistors in the regulated bus comparator.

3. Regulated Bus Comparator Recycling

a. STATEMENT OF PROBLEM

A regulator fails in orbit and the regulated bus comparator successfully switches the standby regulator on-line. An erroneous unencoded ground command causes the system to switch back to the failed regulator. Because of the 10-second re-triggering delay, automatic switching back to the good regulator does not occur. The spacecraft moves "out of sight" of the ground station before a second ground command can restore operation to the good regulator. Spacecraft failure results due to loss of the regulated bus.

b. PRACTICAL SOLUTION OF PROBLEM

Use a 1-hertz (or other convenient rate) clock pulse to reset the comparator cyclically. This enables automatic switching after the 10-second delay expires.

This approach overcomes the effect of the 10-second delay and, barring failure of the Schmitt trigger, would permit rapid reset to a good regulator. However, should there be a failure of a portion of the comparator preceding the trigger, an oscillatory switching condition would result. The switching period would be governed by the retriggering delay time of 10 seconds. Approximately ten additional components must be added to the RBC board in the control module, as shown in Figure 3, to implement the clocked reset, and to provide immunity to noise on the clock pulses.

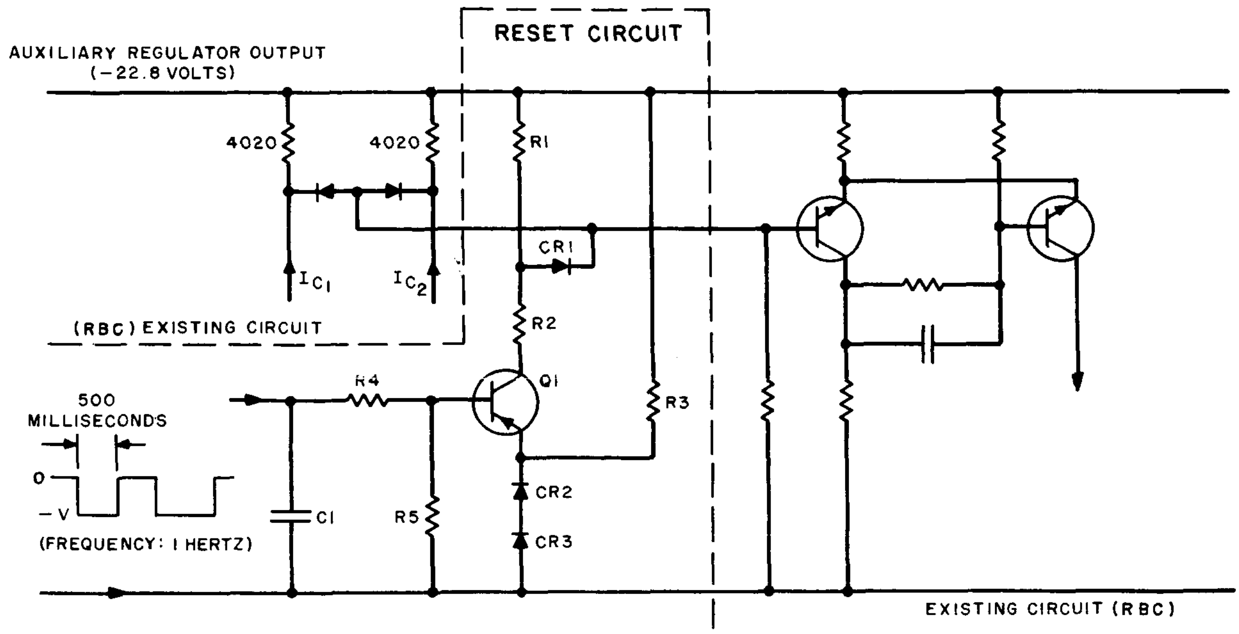


Figure 3. Regulated Bus Comparator Reset Circuit, Schematic Diagram

The response period of the modified regulated bus comparator will be increased by approximately 500 milliseconds. Because of the operation of the reset circuitry, the RBC will not begin switching regulators during the ON cycle of Q1. If the regulated bus voltage should deviate from the specified limits at the beginning of the ON cycle of Q1, it will remain in this condition for 500 milliseconds, after which Q1 will turn OFF, and the RBC will proceed to switch regulators normally. If the regulated bus voltage should deviate from the specified limits during the OFF cycle of Q1, the regulated bus comparator will switch regulators in the normal fashion, with only the time delay designed into the comparator. Thus, the response of the regulated bus comparator may increase by an additional 500 milliseconds, depending on when the bus voltage deviates relative to the 1-hertz input cycle.

This modification is expected to be completed in the next quarterly period.

C. BREADBOARD TESTS

An interface test to determine the electrical compatibility of the RTG converters with the Nimbus-B power subsystem was performed at General Electric Co. Valley Forge, Pennsylvania during the period from August 30 through September 2, 1966.

The PWM regulator operated very satisfactorily with and without the RTG converters on the regulated bus. In fact, the only noticeable change in regulator performance with the RTG converter on the regulated bus was an increase in regulated bus ripple content of approximately 20 millivolts. This increased the total ripple at +25°C to 70 millivolts, which is within the 100-millivolt ripple specification.

D. MECHANICAL DESIGN

1. General

The internal packaging design configuration presented in Figure 91 of Quarterly Report No. 3, showing parts relocation due to Contract Modification No. 3, has not been changed during this quarter. Changes in printed-circuit boards, hard-wired fuse boards and unit internal wiring due to Contract Modification Nos. 7 and 9 were started and partially completed during this quarter.

2. Printed-Circuit and Fuse Boards

Additional fuses and changes in fused line requirements specified in Contract Modification No. 7 required redesign of the two hard-wired fuse boards and modification of the control module unit wiring. Redesign and rework of completed boards and unit wiring for Engineering Models No. 1 and 2 were completed during this quarter. Since NASA has not indicated a list of specific fuse sizes for a particular fused function, fuses used on the engineering model fuse boards were based upon those recommended by RCA in NB-SP-PO-073 letter dated August 11, 1966. These fuses are listed in Table 2.

Redesign of the A6 printed-circuit board and associated unit internal wiring was started during this quarter. The new design will add the trickle charge override command verification telemetry circuit requested in Contract Modification No. 9. Redesign and rework of engineering model parts will be complete early in September.

Redesign of the A7 printed-circuit board was also started during this quarter. The modified board will include a reset circuit in the regulated bus comparator per Contract Modification No. 9. Engineering and drafting effort to modify the existing board design is in process and rework of the existing engineering model boards is being accomplished. Board modifications are scheduled for completion early in September.

Modification of the A5 printed-circuit board drawings and rework of the engineering model boards was completed during this quarter. This change, accomplished per NASA directive, will enable the Regulated Bus Comparator circuit to accept a ground command signal at the clock bus voltage level.

TABLE 2. FUSES SELECTED FOR NIMBUS-B POWER SUBSYSTEM

Fuse Designation	Function	Steady Current (amperes)	Transients*		Pico Fuse Size
			Current (amperes)	Period (milliseconds)	
J5-25-26	RTG DC-DC Converter 1	1.0	N	—	2
J5-47-48	RTG TM Module 1	0.03	0.3	0.5	1
J8-31	Beacon Master Power	0.133	U	U	1/2
J6-28-29	HDRSS A	0.94	4.8	140	4
J6-48-25	Att. Cont. Fine HTR.	1.0	N	—	2
J6-47	Att. Cont. Pot.	0.25	N	—	1/2
J6-32	Spare	—	—	—	5
J6-33	S-Band B Transmitter	1.63	2.0	800	3
J6-46	IFB S-Band A Relay	0.081	N	—	1/4
J6-45	S-Band A and B Relay Power	0.162	N	—	3/8
J5-32	IFB T-M Power Switched	0.25	N	—	1/2
J8-27-28	Spare	—	—	—	5
J7-48	IDCS Camera and Electronics	0.520	2.0	0.5	1
J7-40	IDCS RTTS Transmitter Power	0.95	5.6	0.045	2
J7-45	PCM Record 1 and 2 Relay Power	0.016	U	U	1/8
J7-28-29	IRIS Electronics and Heater	1.0	U	U	3
J7-44	PCM Recorder 1	0.50	U	U	1-1/2
J7-42	PCM Channel 1	0.062	3.0	0.04	1/4
J7-49	PCM Emergency Power	0.093	U	U	3/8
J7-23-24	RMP Electronics	0.85	U	U	3
J6-49	CLK Bus A Spare	—	—	—	1
J8-23-24	CLK A DC-DC Converter	0.29	U	U	1.0
J8-32	CLK A Master Oscillator	0.014	U	U	1/8
J5-29-30	RTG DC-DC Converter 2	1.0	N	—	2
J5-49-50	RTG TM Module 2	0.03	0.3	0.5	1/8
J5-44	IFB MRIR RAD.	0.095	N	—	1/4

* N designates none; U designates not known

TABLE 2. FUSES SELECTED FOR NIMBUS-B POWER SUBSYSTEM (Continued)

Fuse Designation	Function	Steady Current (amperes)	Transients*		Pico Fuse Size
			Current (amperes)	Period (milliseconds)	
J5-45	MRIR Electronics and T-M	0.80	2.0	3	2
J5-46	IFB Beacon Back-up	0.133	U	U	1/2
J6-30-31	HDRSS B	0.94	4.8	140	4
J6-26	HRIR Radiometer	0.053	N	—	1/8
J6-27	IFB S-Band B Relay	0.081	N	—	1/4
J7-26-25	Spare	—	—	—	5
J7-32-19	HRIR Electronics	0.167	0.50	200	1/2
J7-30-31 J7-46-47	IRIS	4.4	22	2.5	10**
J7-41	PCM Recorder 2	0.50	U	U	1-1/2
J7-43	PCM Channel 2	0.062	3.0	0.04	1/4
J8-49	S-Band A Transmitter	1.63	2.0	800	3
J8-29 J8-30	MUSE	0.115	0.70 0.30	0.5 1.0	1/4
J8-45 J8-46	SIRS	0.82	1.50 1.42	0.5 1 second	2
J5-27	Compensation Loads	1.3	N	—	3
J5-31	Day/Nite Sw. Relay Power	0.2	N	—	3/8
J6-50	CLK Bus B Spare	—	—	—	1/2
J8-25 J8-26	CLK B DC-DC Converter	0.29	U	U	1.0
J8-33	CLK B Master Oscillator	0.019	U	U	1/8
J8-48	CLK B Receiver (AM)	0.20	U	U	0.5
J5-22	Bi-Phase Repeater Relay Power	0.081	N	—	1/4
J7-22	RMP Heater	0.48	N	—	1
J7-21	RTTS HAX	0.027	N	—	1/8

* N designates none; U designates not known
** Two size 5 (5-ampere) Pico fuses in parallel

TABLE 2. FUSES SELECTED FOR NIMBUS-B POWER SUBSYSTEM (Continued)

Fuse Designation	Function	Steady Current (amperes)	Transients*		Pico Fuse Size
			Current (amperes)	Period (milliseconds)	
J8-22	CLK A Keying	0.0005	U	U	1/8
J8-21	CLK B Keying	0.0005	U	U	1/8
J5-23	Internal TM Power (IFB)	0.0005	N	—	1/8

* N designates none; U designates not known

3. Connectors and Wiring

The connector function assignment as presented in Quarterly Report No. 3 remained unchanged during this quarter. Modifications in connector pin assignment and the deletion of connector mechanical keying per Contract Modification No. 7 were incorporated into unit drawings and engineering model hardware.

4. Weight

The estimated total weight of the control module is 21.62 pounds. The reduction from 23.82 pounds previously reported in Quarterly No. 3 is the result of including actual weights for some subassemblies in the new estimate. The new estimate is broken down as follows:

(1)	Housing, covers and brackets	6.43 pounds
(2)	Board assemblies, including components (11)	2.59
(3)	Harness board assembly, connectors, harness, terminal boards and miscellaneous electronic components	3.53
(4)	Capacitor and heat sink assemblies, including components (4)	3.38
(5)	Miscellaneous electronic parts, hardware, conformal coating and EMI filters	5.69
	Total Weight	21.62 pounds

SECTION III
STORAGE MODULE

A. GENERAL

Work performed during this reporting period in connection with the development of the storage module consisted of the following:

- Continued the analysis of "Crane" data on General Electric Nimbus-type storage cells;
- Performed a parametric study on General Electric and Gulton Nimbus-type storage cells;
- Updated the weight analysis for the storage module;
- Completed a prototype-level vibration test on one engineering model of the storage module; and
- Developed and incorporated a modification to the battery disconnect circuit.

B. ANALYSIS OF "CRANE" DATA

Earlier data presented in the second quarterly report have been updated. The end-of-charge and end-of-discharge voltages are plotted in Figure 4.

The average end-of-discharge voltages obtained during 5000 cycles of the Crane tests are presented graphically in Figure 5. The curves are based on data for the 15-percent depth of discharge of General Electric cells.

C. PARAMETRIC STUDY OF NIMBUS B STORAGE CELLS

1. Objective

A Parametric Study Test Program was performed to obtain specific data on the electrical characteristics of the nickel-cadmium cells for input to the computer program and to establish confidence in the adequate performance of the cells for the prototype and flight requirements. The program was run simultaneously with prime source (General Electric) and secondary source (Gulton) cells.

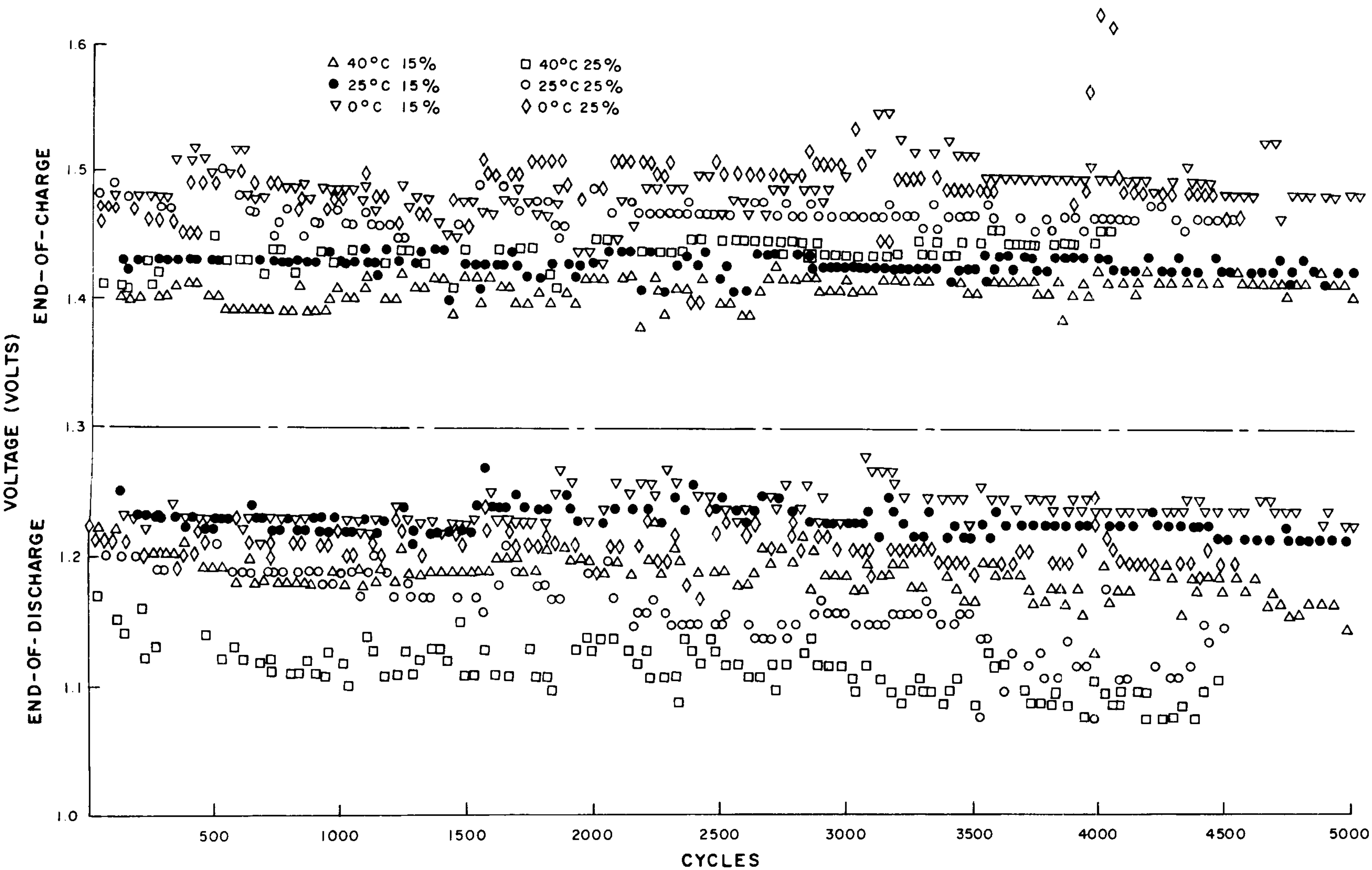


Figure 4. General Electric Cells, Average Cell Voltage Versus Cycle

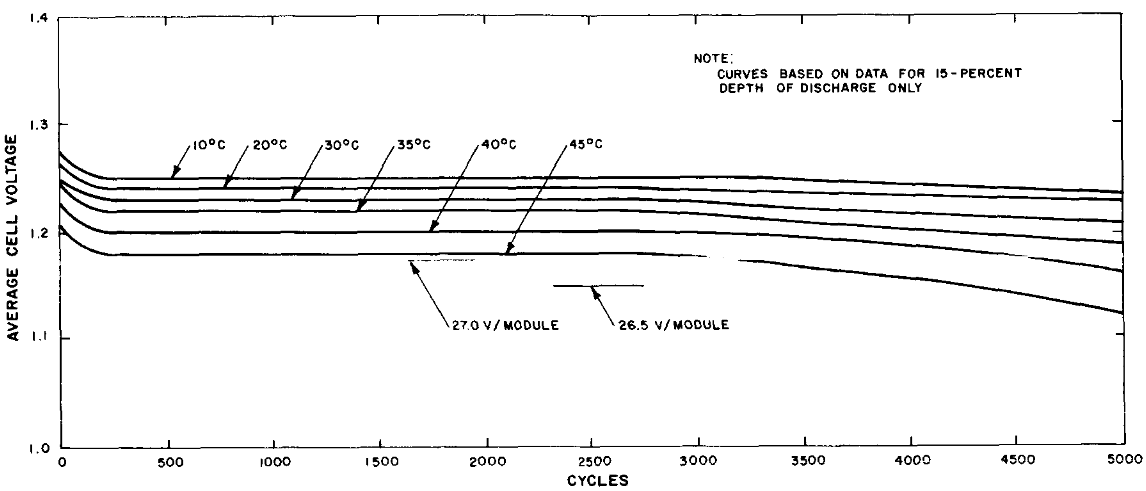


Figure 5. General Electric Cells, Average End-of-Discharge Cell Voltage Versus Cycle

2. Summary

Charge and discharge tests were run on 92 Nimbus storage cells. Fifty-four cells procured from General Electric and 38 cells procured from Gulton Industries were included. The cells were tested at charge rates from 0.400 to 1.200 amperes and at discharge rates from 0.69 to 2.0 amperes. The tests were performed at temperatures of 15, 25, 35, and 45° C. Forty-one cells (23 General Electric and 18 Gulton) were equipped with pressure gauges.

3. Test Description

a. CELL GROUPINGS

The cells were arranged in four similar groups and each group was maintained at a specific temperature throughout the test. The composition of each group is shown in Table 3. The cell serial numbers and the position of each cell in each group are indicated in Table 4. General Electric cells can be identified by their hyphenated serial number. Cells equipped with pressure gauges are denoted by an asterisk.

TABLE 3. COMPOSITION OF CELL GROUPINGS

Group	Temperature (°C)	Quantity of Cells			
		General Electric		Gulton Industries	
		Regular	With Pressure Gauge	Regular	With Pressure Gauge
1	15	8	6	5	4
2	25	8	5	5	5
3	35	8	6	5	4
4	45	7	6	5	5

b. TEST PROCEDURE

Before the start of Test Number 1, the cells were charged. A full charge was ensured by charging for 16 hours at 0.45 amperes and at the same temperatures as those for Test Number 1.

A series of twelve tests was run on these cells to obtain the basic parametric data which will be used as the input to the computer study. In addition to these twelve tests, six tests were run to obtain data concerning the launch phase of the Nimbus B mission. Following the 18th tests all cells were completely discharged.

Table 5 lists the tests with the discharge and charge times, the discharge and charge rates, the cell temperatures, and remarks. The temperatures are actual cell temperatures, not ambient air temperatures.

During the tests, a complete record was maintained of individual cell voltages, charge and discharge currents, cell temperatures, and cell pressures. The voltages and current were monitored with a digital voltmeter and recorded by a tape printer. The temperature was monitored with a strip chart temperature recorder and readings were manually recorded on a data sheet at appropriate intervals. The cell pressures were monitored with the pressure gauge attached permanently to the cells and were manually recorded on a data sheet at appropriate intervals. The schedule for the test readings is shown in Table 6.

TABLE 4. CELL POSITION AND SERIAL NUMBER

Position	Cell Serial Number			
	Group 1	Group 2	Group 3	Group 4
1	381*	394*	402*	396*
2	366	367	369	371
3	399*	401*	407*	403*
4	372	373	374	376
5	377	378	379	382
6	385	387	388	389
7	390	406*	393	412*
8	8-81	391	10-113	395
9	14-7*	9-5	14-49*	14-50*
10	13-73	13-74	13-75	10-115
11	405*	415*	417*	418*
12	14-5	14-6	14-8	13-1
13	414*	421*	423*	427*
14	15-1	15-2	15-43	14-10
15	14-57*	14-22*	14-60*	14-61*
16	15-8	15-17	15-58	15-73
17	14-65*	14-59*	14-98*	15-9*
18	16-6	16-17	16-97	16-52
19	15-23*	14-76*	15-80*	15-85*
20	18-35	18-36	18-27	18-31
21	15-87*	15-64*	19-2*	19-3*
22	19-18	19-29	19-23	19-24
23	19-6*	19-1*	19-8*	19-4*

Note: 1. General Electric cells have hyphenated serial numbers. Gulton cells have a three digit serial number.
2. Cells equipped with pressure gauges are identified by an asterisk.

TABLE 5. TEST PARAMETERS

Test No.	Temperature (° C)	Discharge Rate (amperes)	Discharge Time (minutes)	Charge Rate (amperes)	Charge Time (minutes)	Remarks
1	15 25 35 45	1.0 1.0 1.0 1.0	54 54 54 54	0.40 0.40 0.40 0.40	205 205 205 205	Terminate charge and start test No. 2
2	15 25 35 45	2.0 2.0 2.0 2.0	54 54 54 54	0.40 0.40 0.40 0.40	410 410 410 410	Continue charge into Test No. 3
3	15 25 35 45			0.40 0.40 0.40 0.40	8 hr. 8 hr. 8 hr. 8 hr.	Charge time is continuation of Test No. 2
4	15 25 35 45	1.0 1.0 1.0 1.0	54 54 54 54	0.80 0.80 0.80 0.80	100 100 100 100	Terminate charge and start Test No. 3
5	15 25 35 45	2.0 2.0 2.0 2.0	54 54 54 54	0.80 0.80 0.80 0.80	200 200 200 200	Continue charge into Test No. 6
6	15 25 35 45			0.80 0.80 0.80 0.80	4 hr. 4 hr. 4 hr. 4 hr.	Charge time is continuation of Test No. 5
7	15 25 35 45	1.0 1.0 1.0 1.0	54 54 54 54	1.00 1.00 1.00 1.00	59 65 70 76	Terminate charge as indicated
8	15 25 35 45	2.0 2.0 2.0 2.0	54 54 54 54	1.00 1.00 1.00 1.00	118 130 140 152	Continue charge into Test No. 9
9	15 25 35 45			1.00 1.00 1.00 1.00	1 hr. 2 hr. 3 hr. 4 hr.	Terminate any group if pressure reaches 250 psig.

TABLE 5. TEST PARAMETERS (Continued)

Test No.	Temperature (° C)	Discharge Rate (amperes)	Discharge Time (minutes)	Charge Rate (amperes)	Charge Time (minutes)	Remarks
10	15 25 35 45	1.0 1.0 1.0 1.0	54 54 54 54	1.20 1.20 1.20 1.20	49 54 59 64	Terminate charge as indicated
11	15 25 35 45	2.0 2.0 2.0 2.0	54 54 54 54	1.20 1.20 1.20 1.20	98 108 118 128	Continue charge into Test No. 12
12	15 25 35 45			1.20 1.20 1.20 1.20	1 hr. 2 hr. 3 hr. 4 hr.	Terminate any group if pressure reaches 250 psig
13	15 25 35 45	0.69 0.69 0.69 0.69	80 80 80 80	0.40 0.40 0.40 0.40	207 207 207 207	
14	15 25 35 45	0.69 0.69 0.69 0.69	80 80 80 80	1.20 1.20 1.20 1.20	51 54 60 64	Terminate charge as indicated
15	15 25 35 45	0.69 0.69 0.69 0.69	180 180 180 180	0.40 0.40 0.40 0.40	466 466 466 466	
16	15 25 35 45	0.69 0.69 0.69 0.69	180 180 180 180	1.20 1.20 1.20 1.20	144 124 135 145	Terminate charge as indicated
17	15 25 35 45	0.69 0.69 0.69 0.69	250 250 250 250	0.40 0.40 0.40 0.40	647 647 647 647	
18	15 25 35 45	0.69 0.69 0.69 0.69	250 250 250 250	1.20 1.20 1.20 1.20	158 173 187 201	Terminate charge as indicated

TABLE 6. TEST READINGS SCHEDULE

Test Mode	Readings Taken	
	Voltage and Current (Printer Tape)	Temperature and Pressure (Data Sheet)
Discharge	Within 2 minutes of start Within 2 minutes of end 10-minute intervals	Within 5 minutes of start Within 5 minutes of end
Charge	Within 2 minutes of start Within 2 minutes of end 20-minute intervals	Within 5 minutes of start Within 5 minutes of end 30-minute intervals (10-minute intervals for pressure when pressures are above 200 psig)

4. Test Results

a. NORMAL ORBIT VOLTAGE (FIGURES 6 THROUGH 21)

Figures 6 through 21 present the data from Tests No. 1, 4, 7, and 10. These data represent cell voltage as a function of state of charge during a 54-minute one-ampere discharge followed by a subsequent charge at 0.40, 0.80, 1.00, and 1.20 amperes. Results obtained at 15, 25, 35, and 45° C are included.

In order to present this data in a form most acceptable as input to the computer, the cell voltages are plotted as a function of percentage of rated capacity at 25° C. A value of 270 ampere-minutes is taken as equal to 100 percent of rated cell capacity. Each curve represents a discharge followed by a charge.

b. DEEP ORBIT AND OVERCHARGE VOLTAGE (FIGURES 22 THROUGH 25)

Figures 22 through 25 present the data from Tests No. 2, 3, 5, 6, 8, 9, 11, and 12. Cell voltage is plotted as a function of elapsed time from beginning of discharge during a 54-minute 2-ampere discharge and a subsequent recharge and overcharge at 0.40, 0.80, 1.00, and 1.20 amperes. Results obtained at 15, 25, 35, and 45° C are included.

c. RECHARGE VOLTAGE AFTER LAUNCH (FIGURES 26 THROUGH 29)

Figures 26 through 29 present data from Tests No. 13 through 18. Cell voltage is plotted as a function of charge time for charge rates of 0.40 and 1.20 amperes. Before each charge the cells had been discharged at 0.69 amperes for 80, 180, or 250 minutes. These discharges represent the energy required from the battery during satellite launch, assuming sun acquisition during the first, second, and third orbits, respectively.

d. FULL CAPACITY DISCHARGE VOLTAGE (FIGURES 30 AND 31)

Figures 30 and 31 present the data obtained during the discharge run after Test No. 18. Terminal voltage is plotted as a function of time during a full capacity discharge at 0.69 ampere. The solid lines represent the average of all cells remaining above cut-off voltage, and the corresponding dashed lines represent the voltage of the first cell to become completely discharged (i.e., reach cutoff).

e. COMPARISON OF GENERAL ELECTRIC AND GULTON CELL DISCHARGE VOLTAGE

To compare discharge voltage characteristics of the Gulton and General Electric cells, the average cell voltage was calculated at three points during the discharge run after Test No. 18. These data are as follows:

Temperature 15° C	Discharge Voltage	
Elapsed Time (Minutes)	Gulton	General Electric
10	1.349	1.358
50	1.287	1.297
250	1.228	1.239

Temperature 25° C	Discharge Voltage	
Elapsed Time (Minutes)	Gulton	General Electric
10	1.335	1.340
50	1.290	1.300
250	1.228	1.238

Temperature 35° C Elapsed Time (Minutes)	Discharge Voltage Gulton	General Electric
10	1.329	1.333
50	1.299	1.304
150	1.234	1.242

Temperature 45° C Elapsed Time (Minutes)	Discharge Voltage Gulton	General Electric
10	1.312	1.321
50	1.264	1.278
100	1.232	1.244

f. OVERCHARGE VOLTAGE AND CHARGE CONTROL CURVES (FIGURE 32)

Figure 32 includes the upper and lower voltage control limits recommended for the Nimbus B system. These limits are represented by the two continuous lines.

Also plotted on Figure 32 are the "steady-state" overcharge voltages exhibited during this parametric study at 0.4, 0.8, 1.0, and 1.2 amperes within the temperature range of 15 to 45° C.

g. TAFEL CURVES (FIGURE 33)

Figure 33 includes Tafel curves for these cells. Overcharge voltage versus charge current is plotted for temperatures of 15, 25, 35, and 45° C.

h. TAFEL CURVES COMPARISON BY VENDOR (FIGURE 34)

Figure 34 is a re-plot of the data of Figure 33 with General Electric and Gulton cells plotted separately for comparison.

i. DISCHARGE VOLTAGE COMPARISON BY VENDOR

Figure 35 is a plot of discharge voltage of Gulton and General Electric cells versus load current in the range 0.69 to 2.0 amperes. Data is plotted after 10, 20, and 30 minutes of discharge at constant current.

j. PRESSURE

Forty-one of the cells were fitted with pressure gauges. The internal cell pressure was recorded periodically during the sequence of tests. Pressure data obtained during the tests are listed in Table 7.

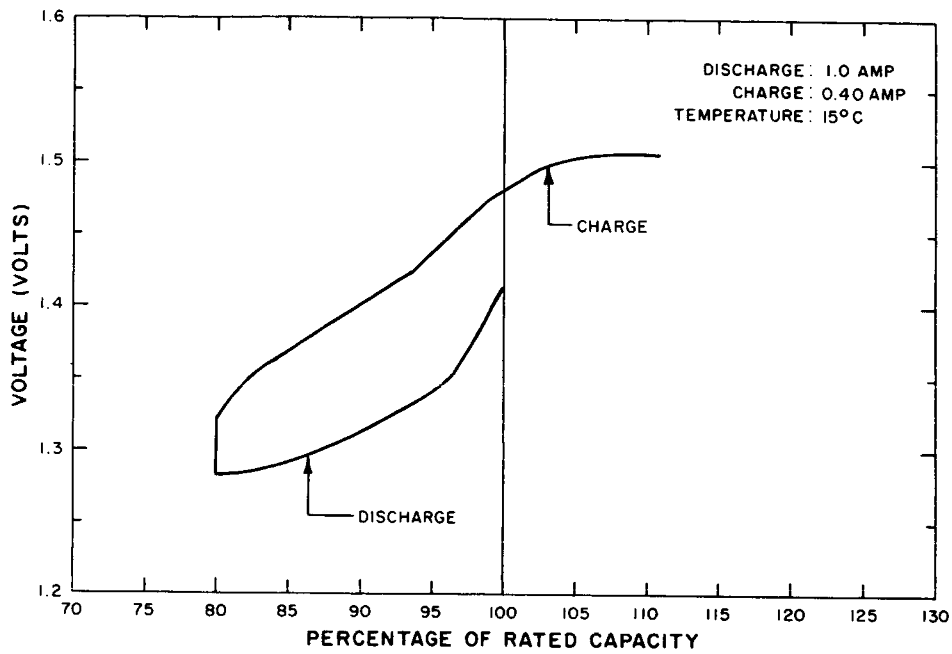


Figure 6. Cell Voltage Versus Charge State, Test No. 1 at 15° C

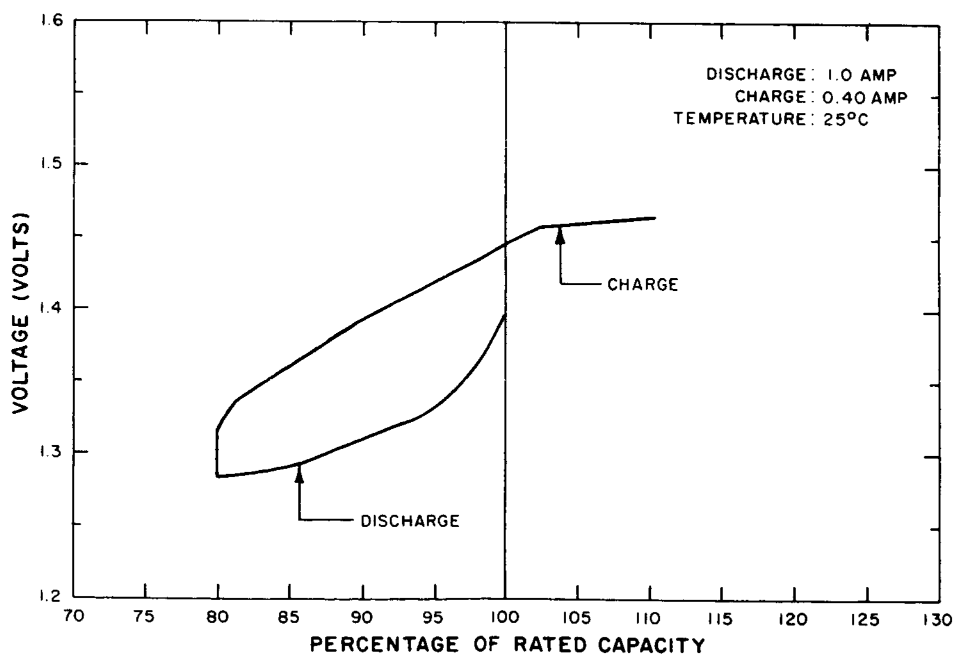


Figure 7. Cell Voltage Versus Charge State, Test No. 1 at 25° C

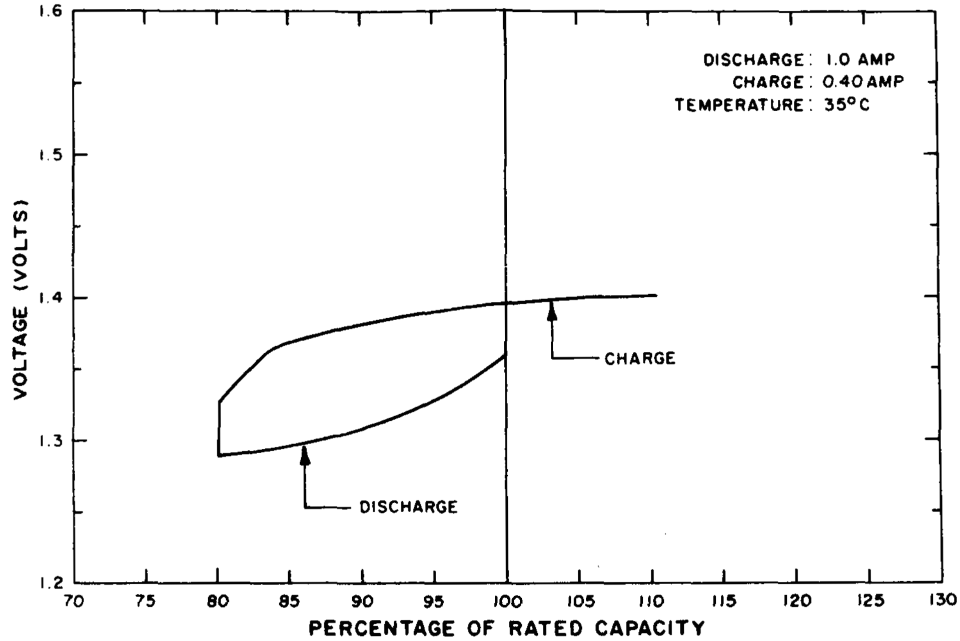


Figure 8. Cell Voltage Versus Charge State, Test No. 1 at 35° C

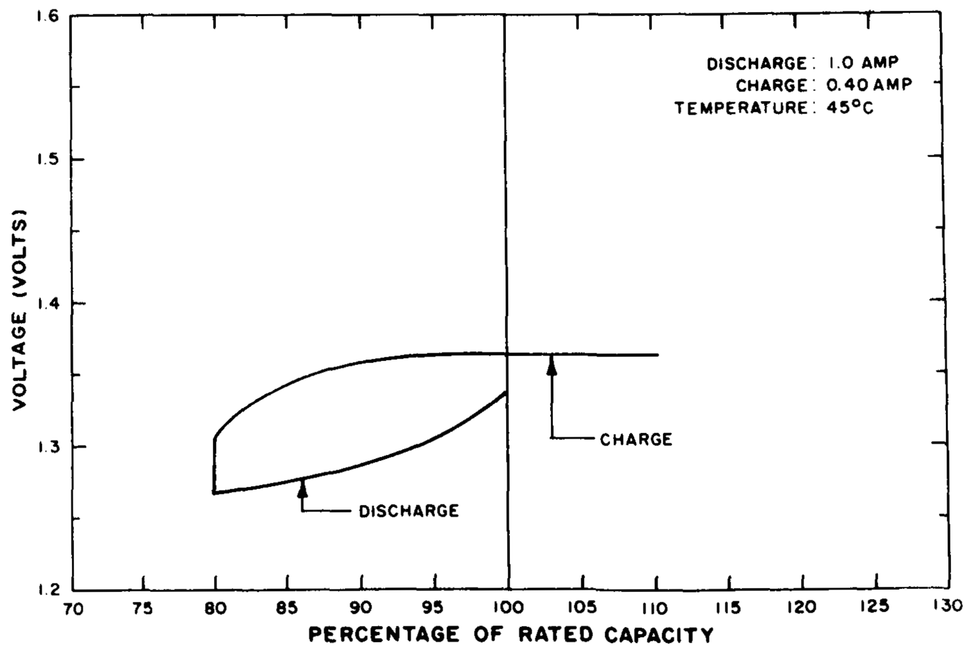


Figure 9. Cell Voltage Versus Charge State, Test No. 1 at 45° C

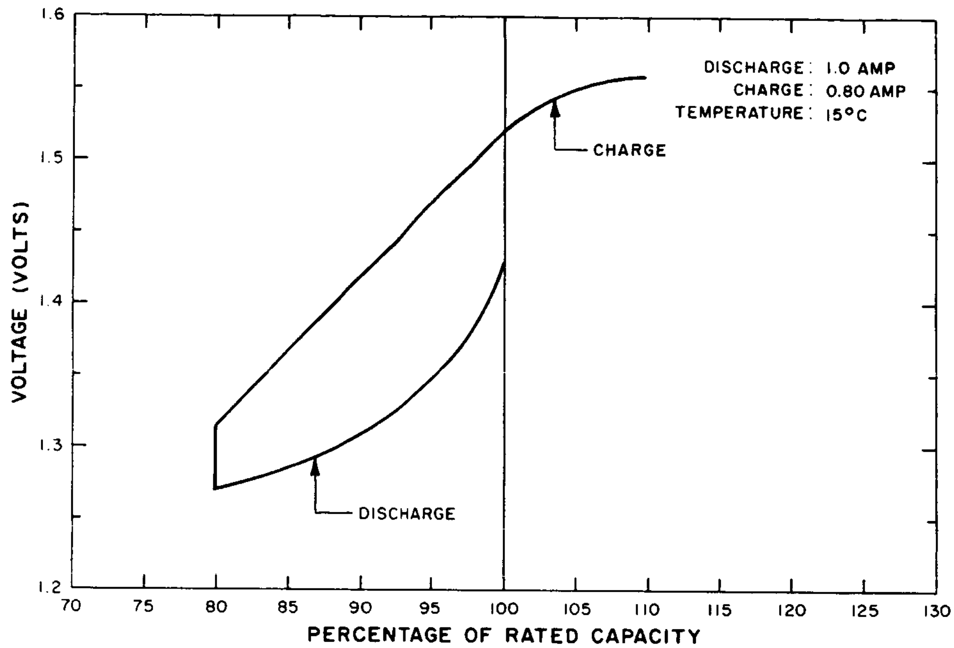


Figure 10. Cell Voltage Versus Charge State, Test No. 4 at 15° C

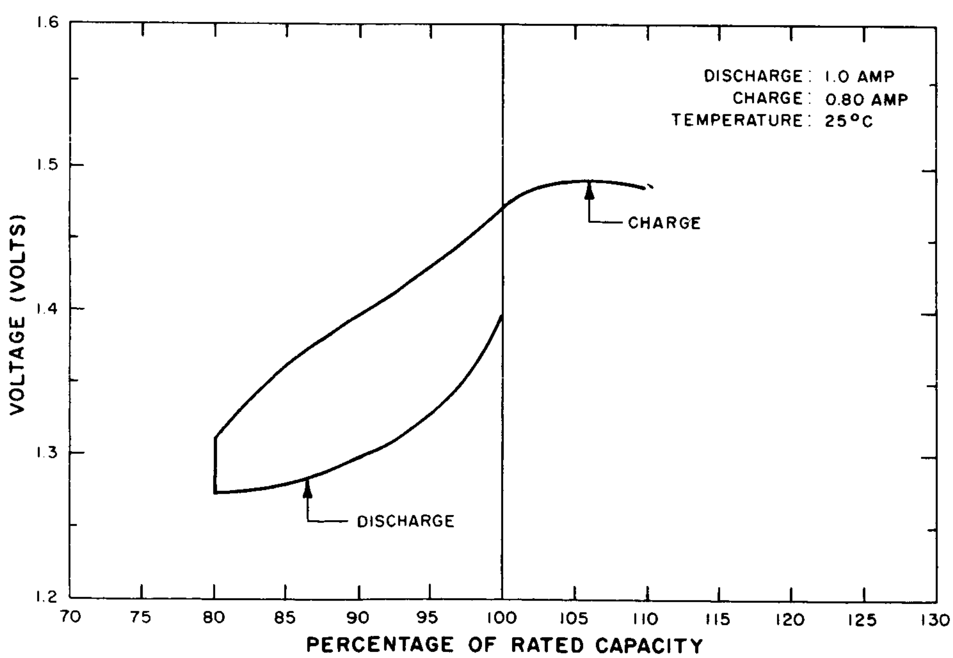


Figure 11. Cell Voltage Versus Charge State, Test No. 4 at 25° C

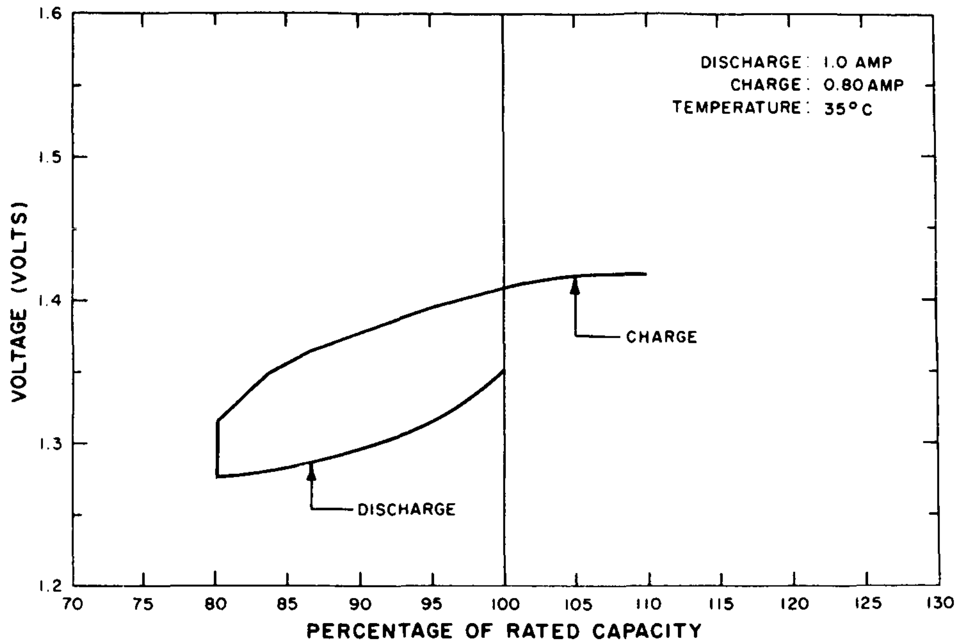


Figure 12. Cell Voltage Versus Charge State, Test No. 4 at 35° C

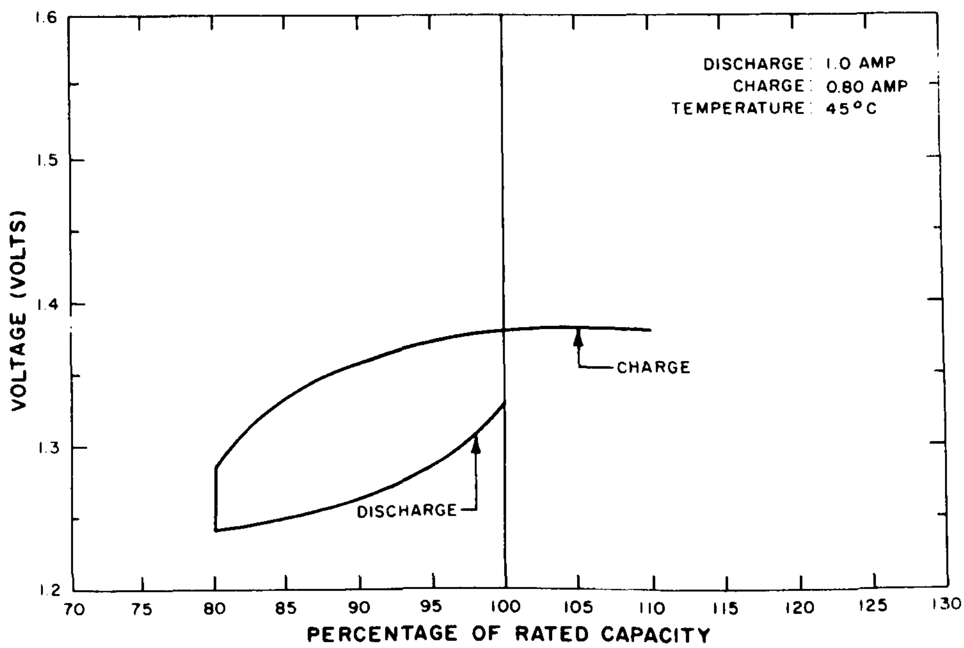


Figure 13. Cell Voltage Versus Charge State, Test No. 4 at 45° C

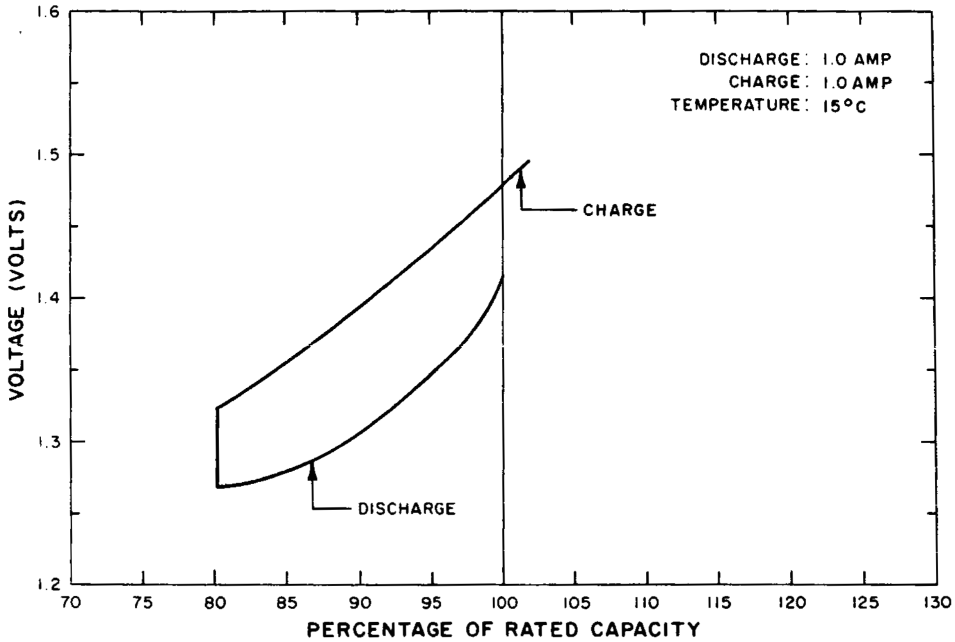


Figure 14. Cell Voltage Versus Charge State, Test No. 7 at 15° C

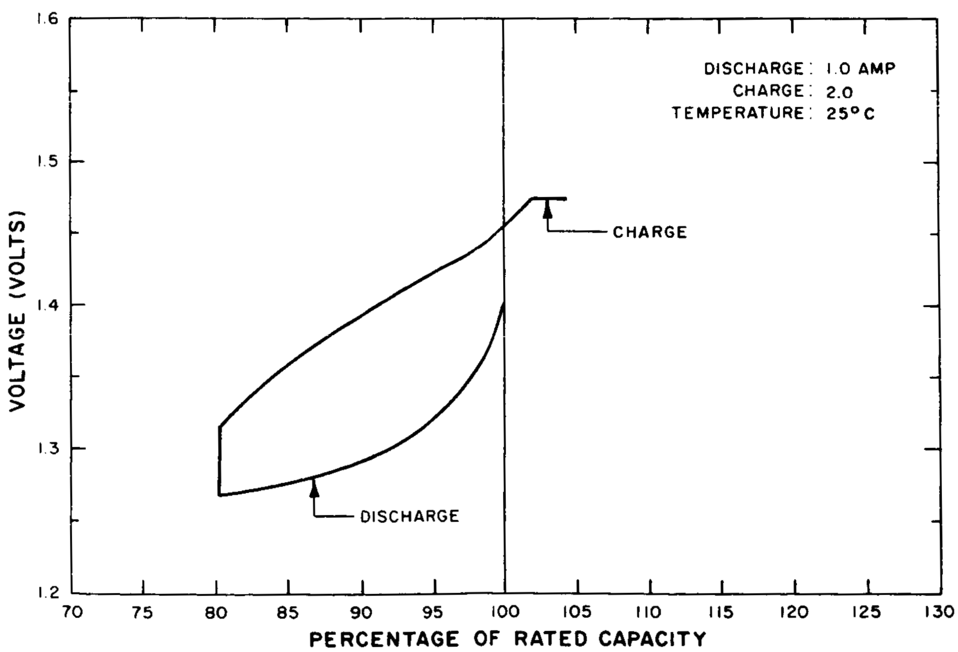


Figure 15. Cell Voltage Versus Charge State, Test No. 7 at 25° C

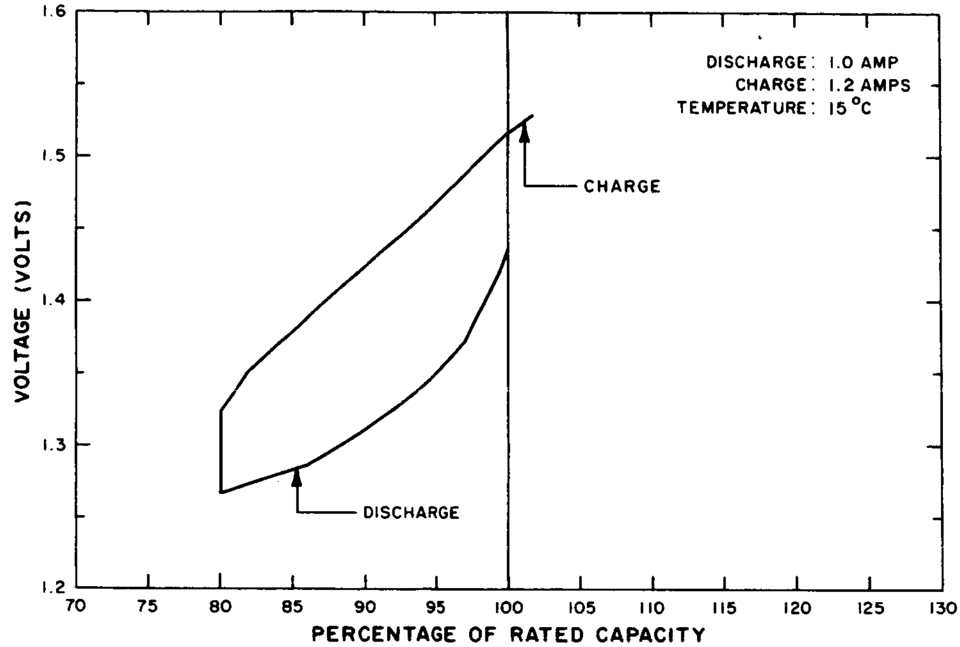


Figure 18. Cell Voltage Versus Charge State, Test No. 10 at 15° C

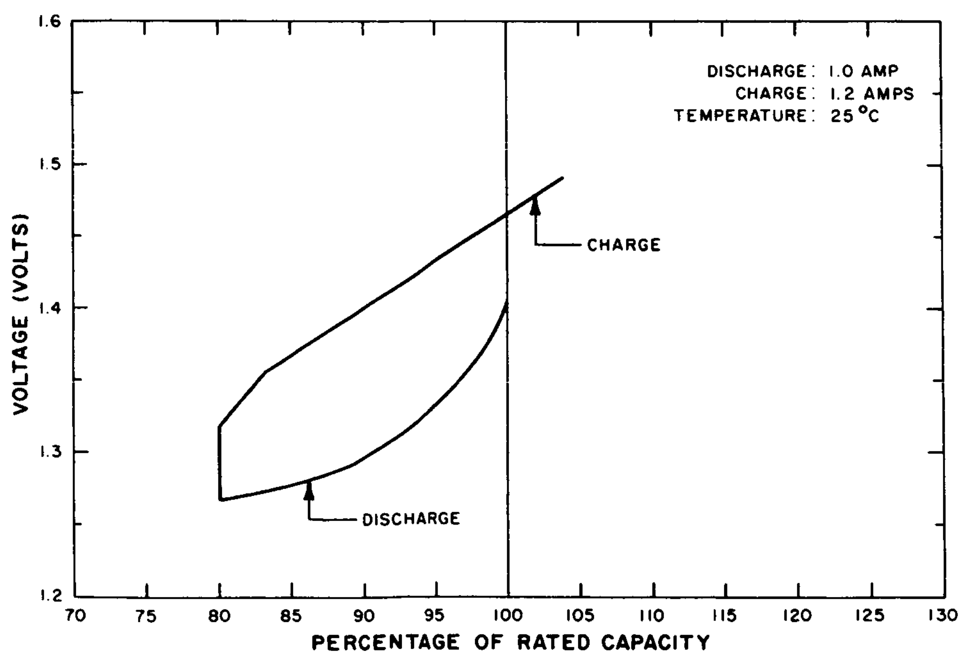


Figure 19. Cell Voltage Versus Charge State, Test No. 10 at 25° C

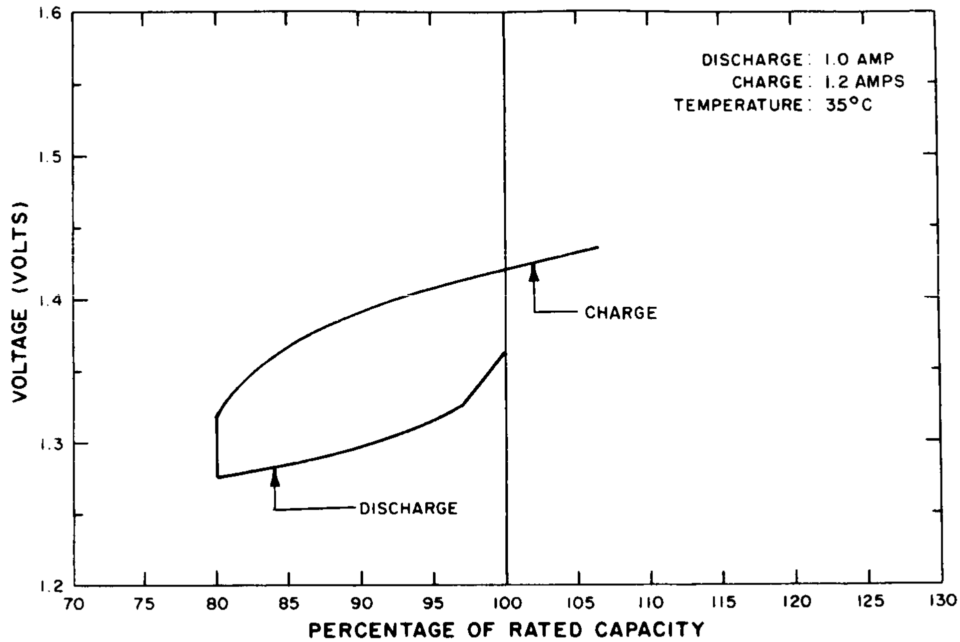


Figure 20. Cell Voltage Versus Charge State, Test No. 10 at 35° C

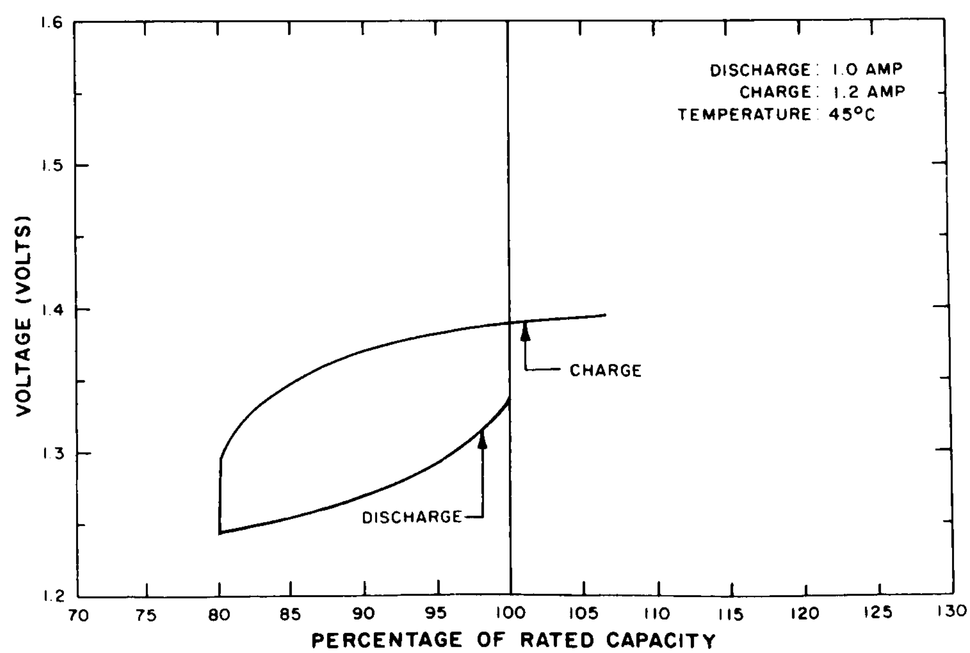


Figure 21. Cell Voltage Versus Charge State, Test No. 10 at 45° C

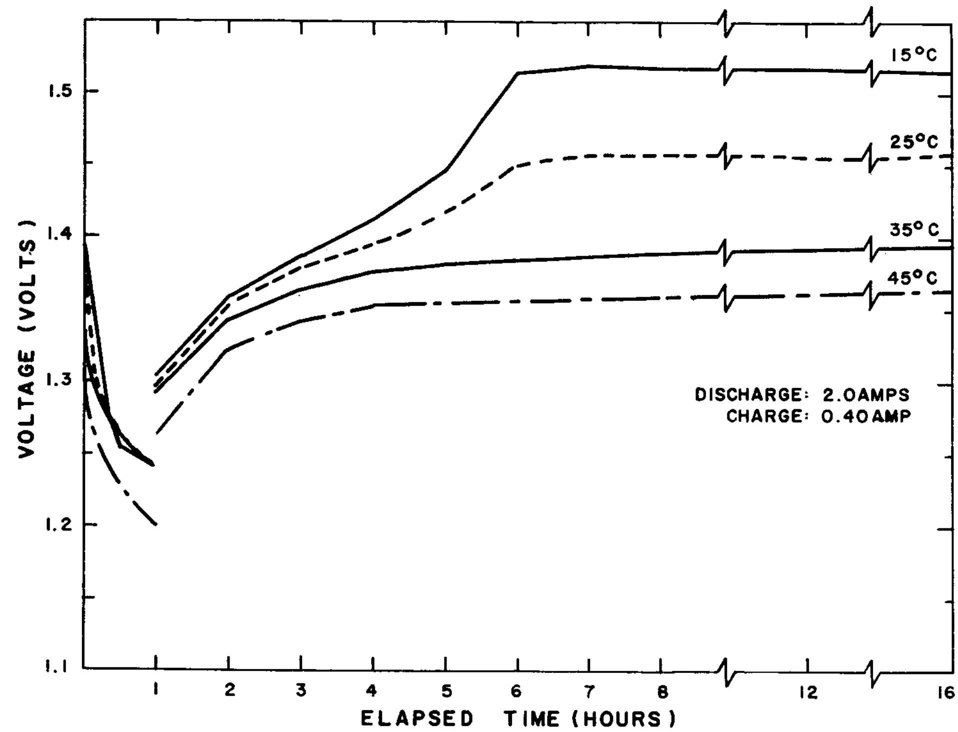


Figure 22. Cell Voltage Versus Elapsed Time, 0.40-Ampere Charge Rate

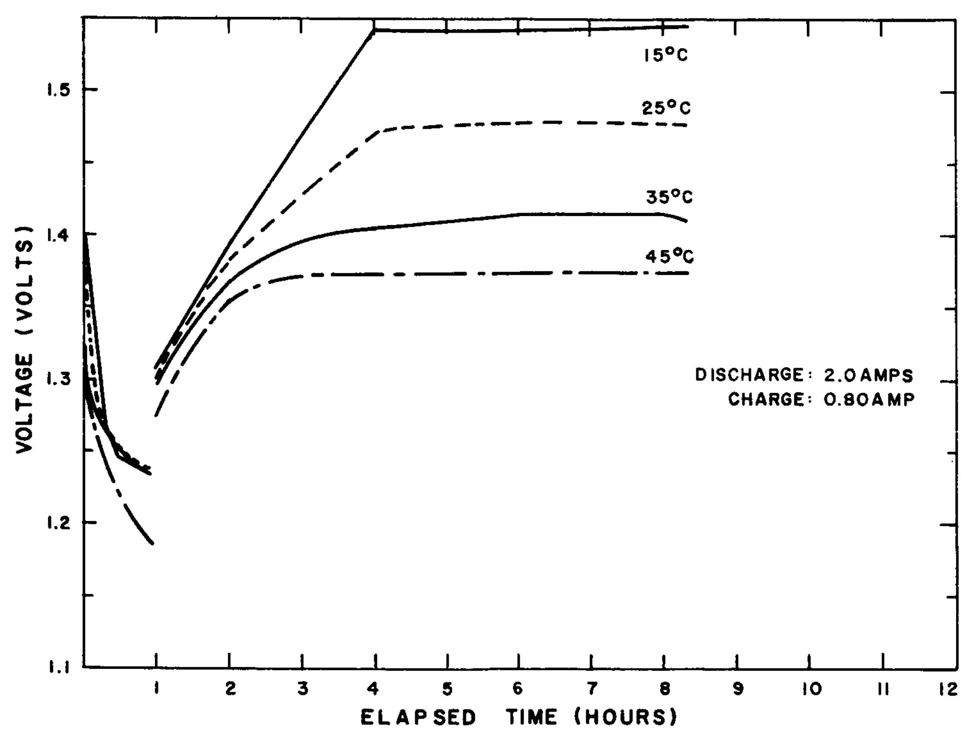


Figure 23. Cell Voltage Versus Elapsed Time, 0.80-Ampere Charge Rate

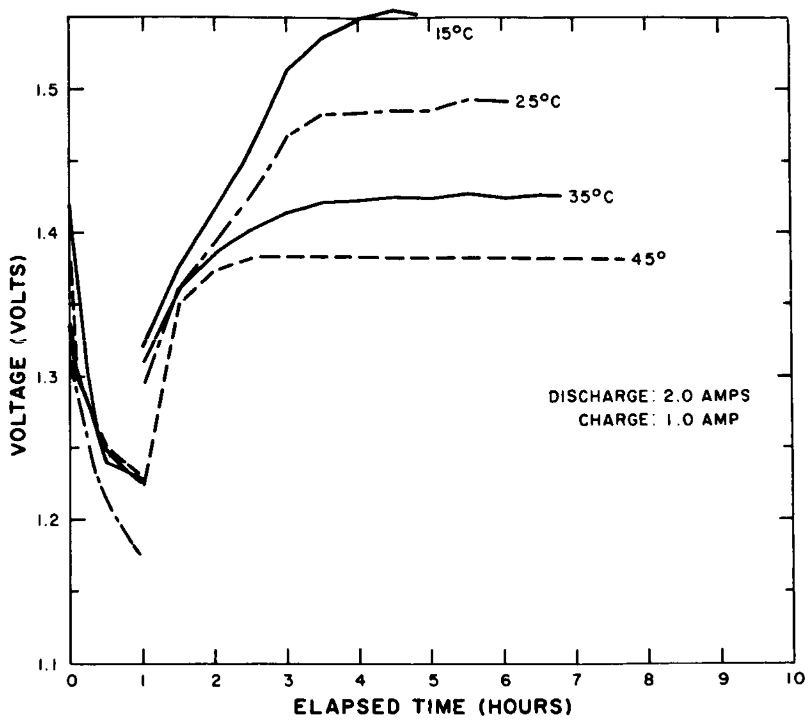


Figure 24. Cell Voltage Versus Elapsed Time, 1.0-Ampere Charge Rate

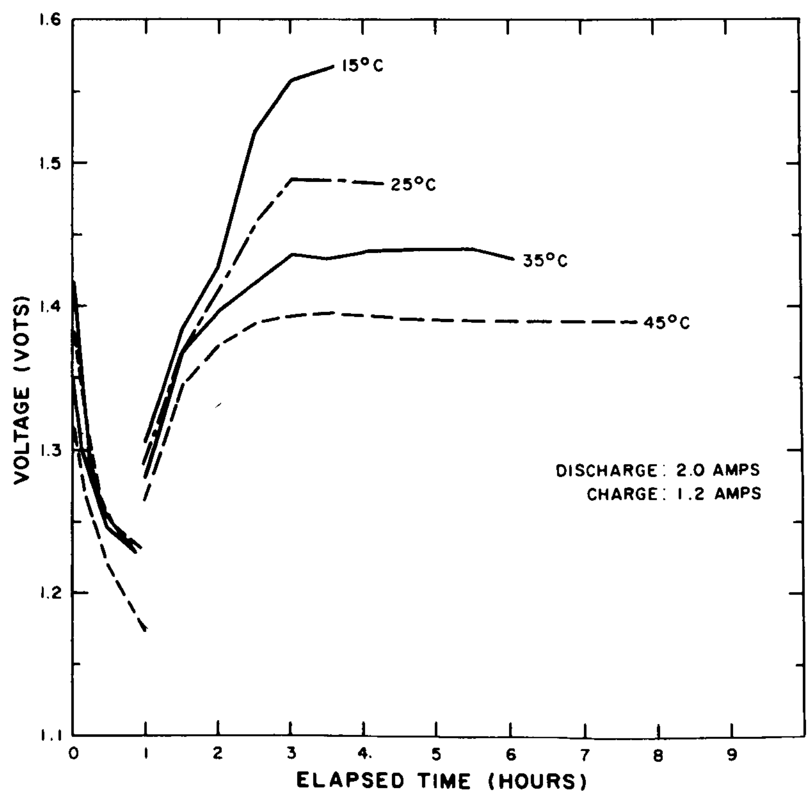


Figure 25. Cell Voltage Versus Elapsed Time, 1.2-Ampere Charge Rate

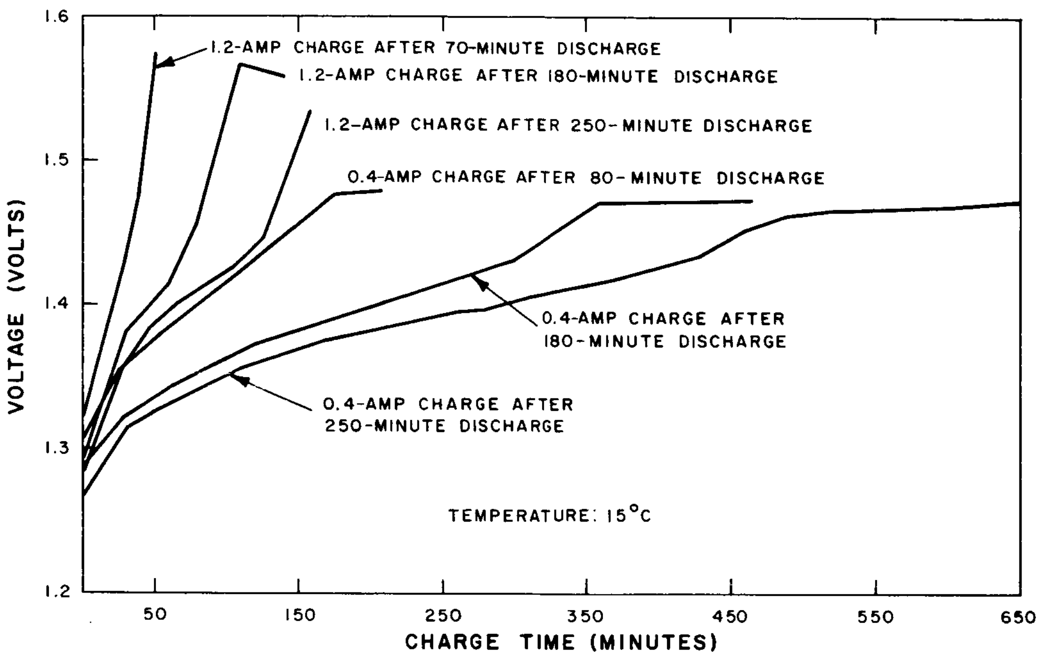


Figure 26. Cell Voltage Versus Charge Time at 15° C

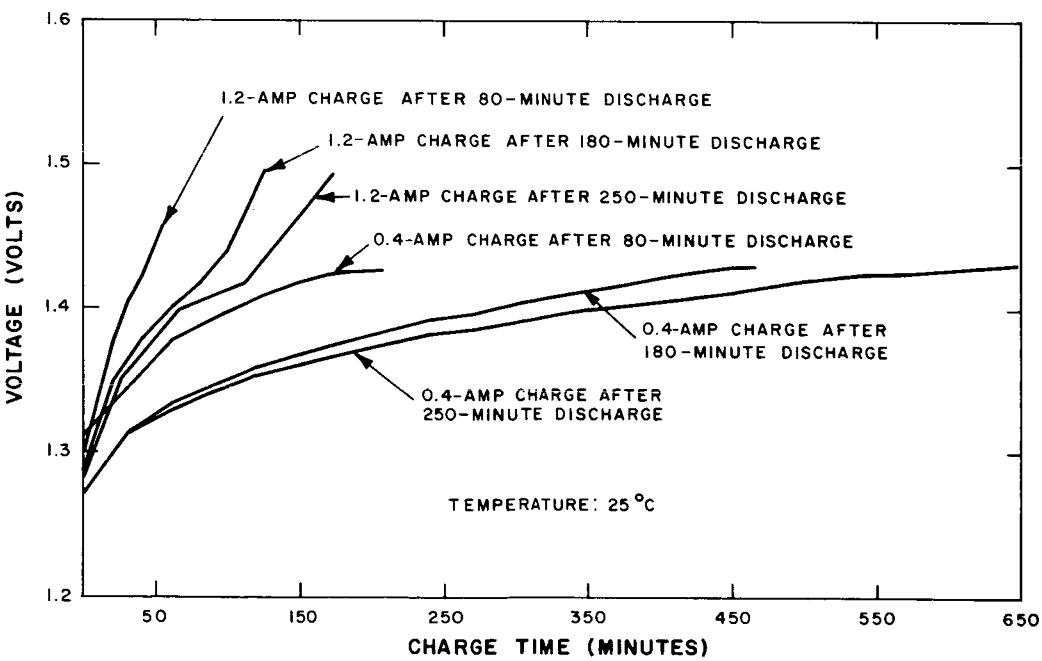


Figure 27. Cell Voltage Versus Charge Time at 25° C

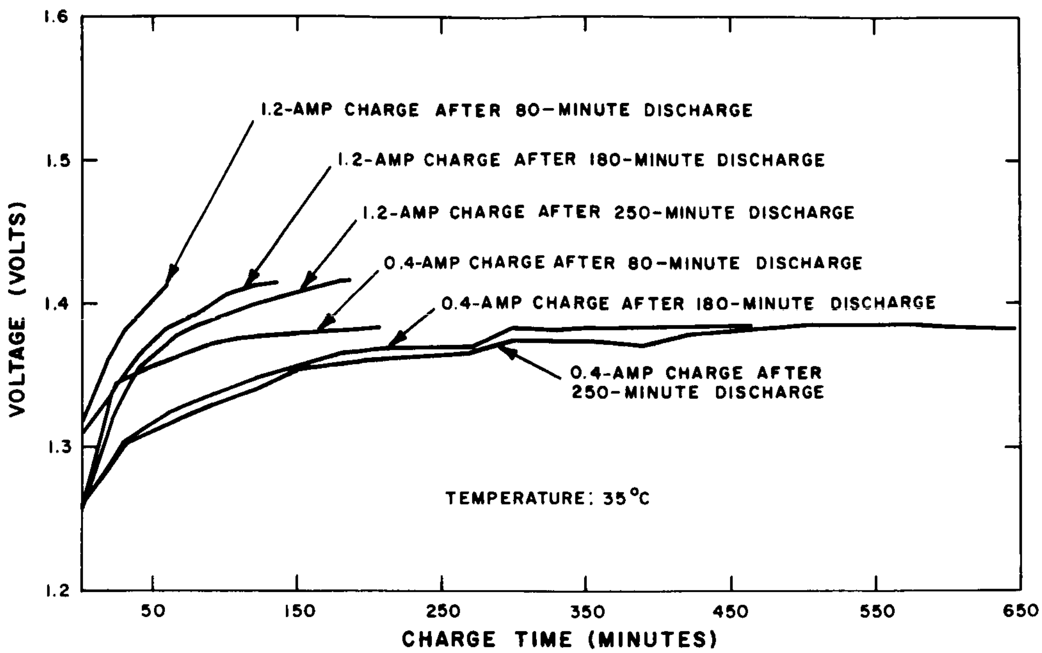


Figure 28. Cell Voltage Versus Charge Time at 35° C

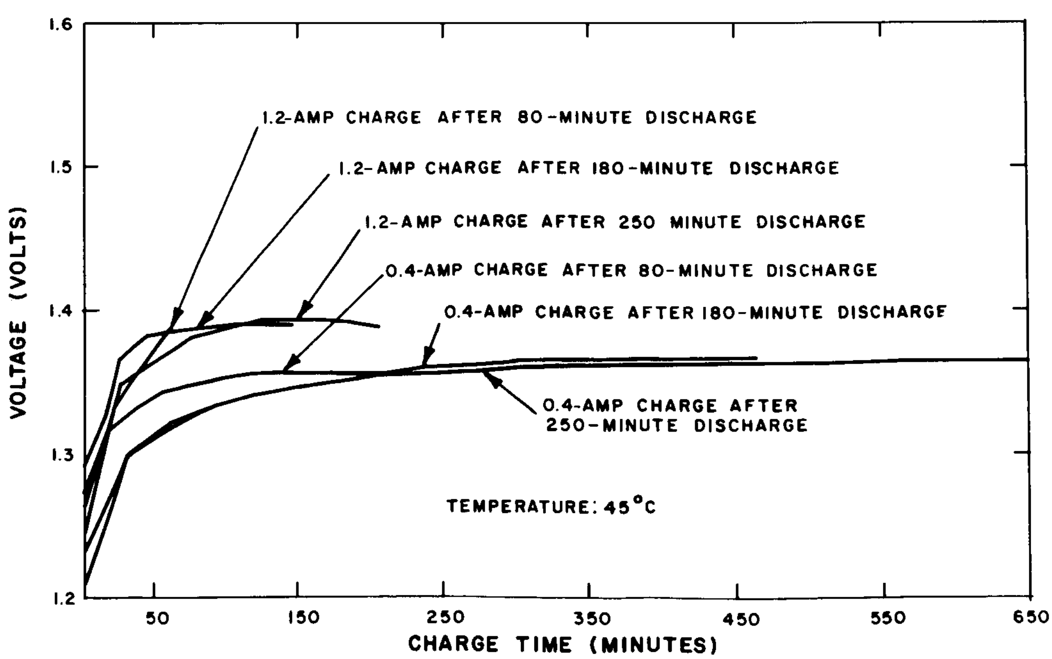


Figure 29. Cell Voltage Versus Charge Time at 45° C

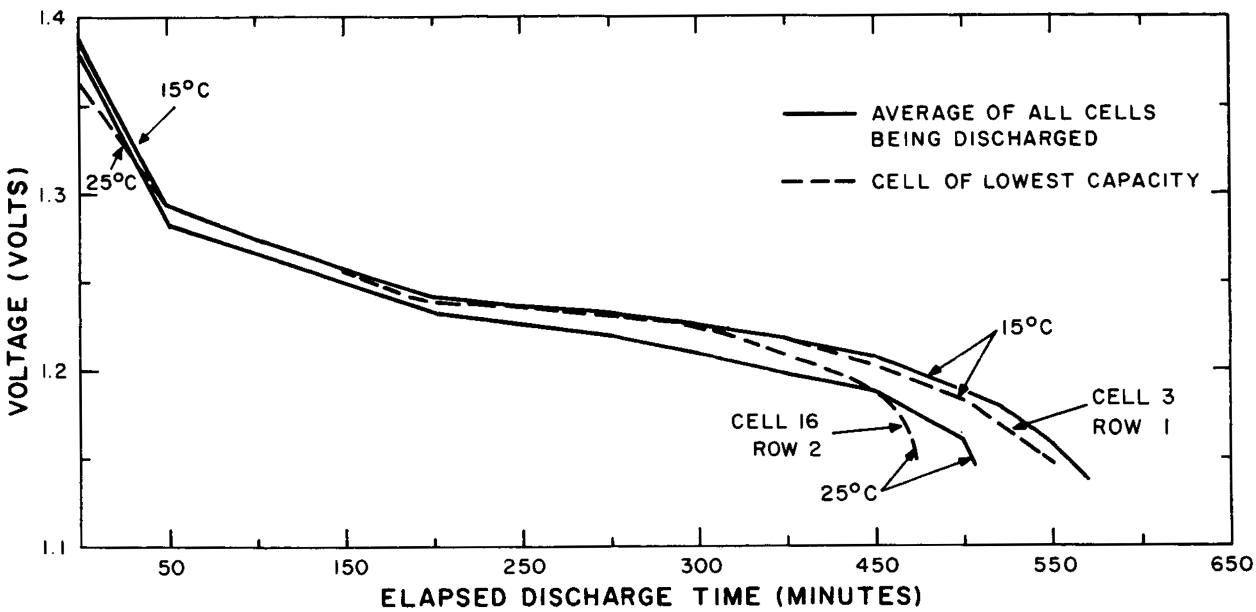


Figure 30. Cell Voltage Versus Elapsed Discharge Time at 15° C and 25° C

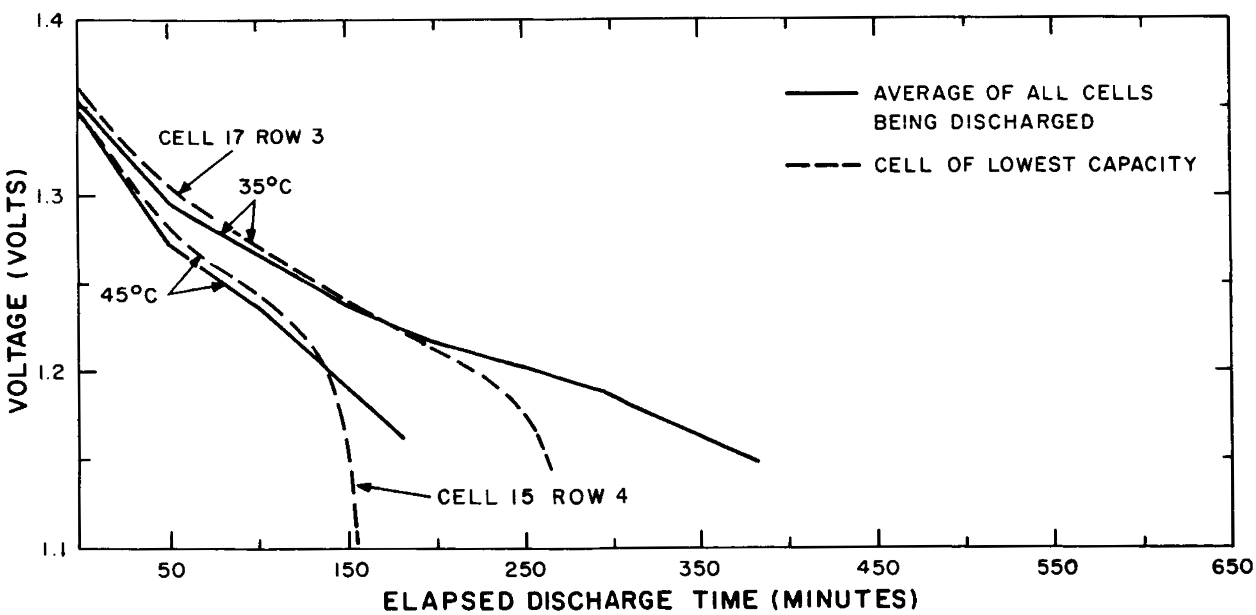


Figure 31. Cell Voltage Versus Elapsed Discharge Time at 35° C and 45° C

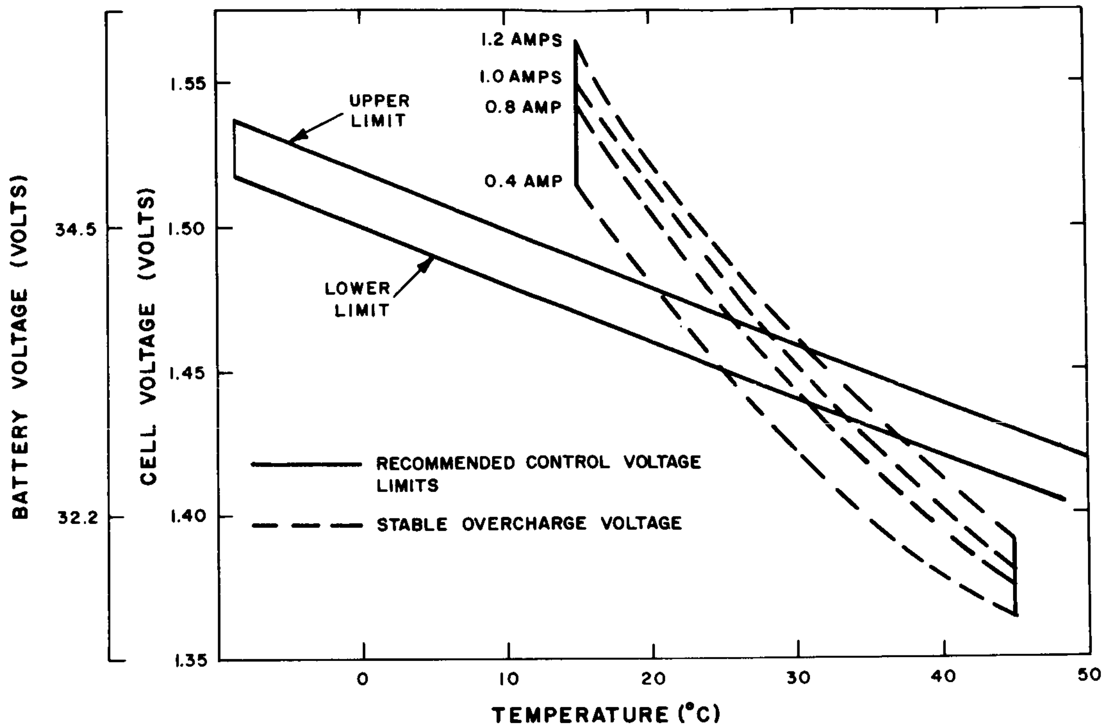


Figure 32. Recommended Control Voltage Limits and Stable Overcharge Voltages Versus Temperature

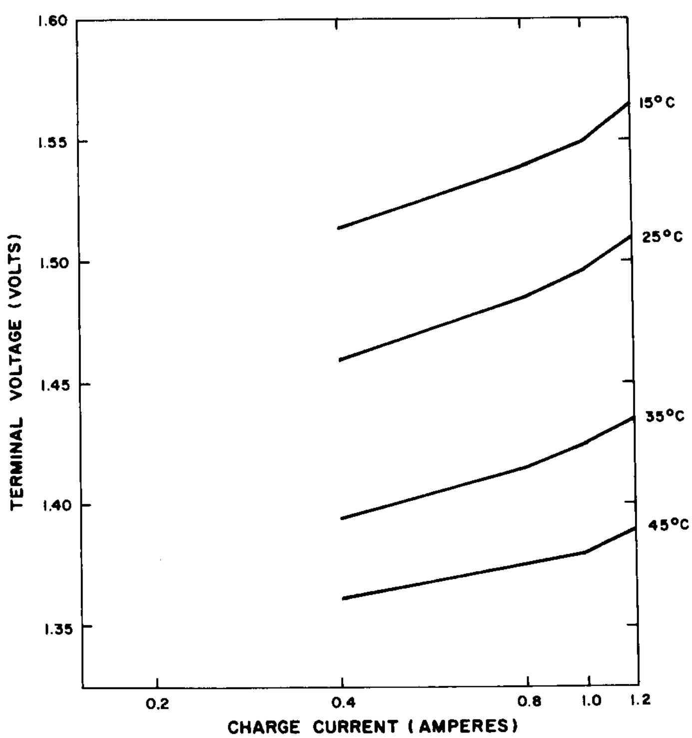


Figure 33. Cell Voltage Versus Charge Current

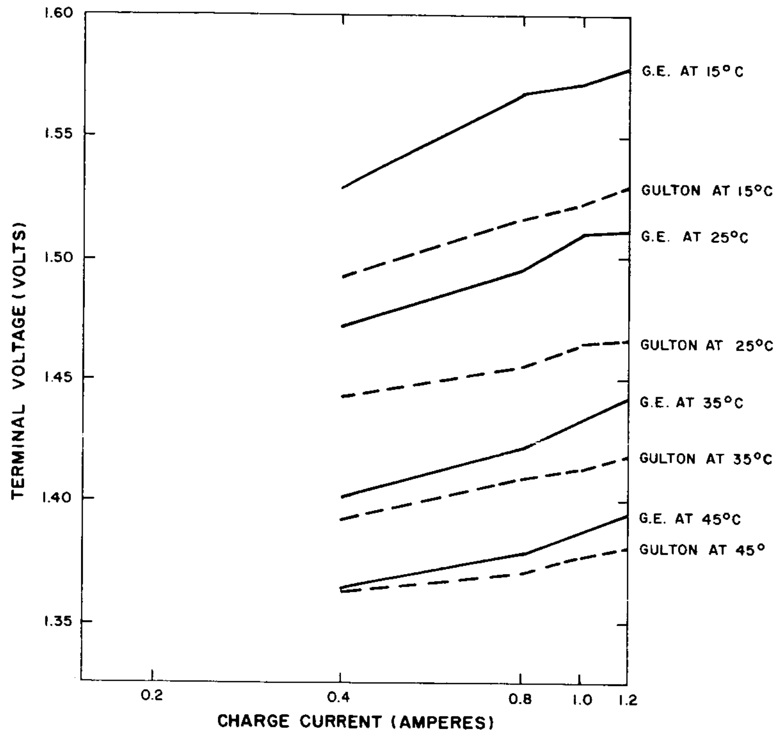


Figure 34. Comparison of General Electric and Gulton Cells — Cell Voltage Versus Charge Current

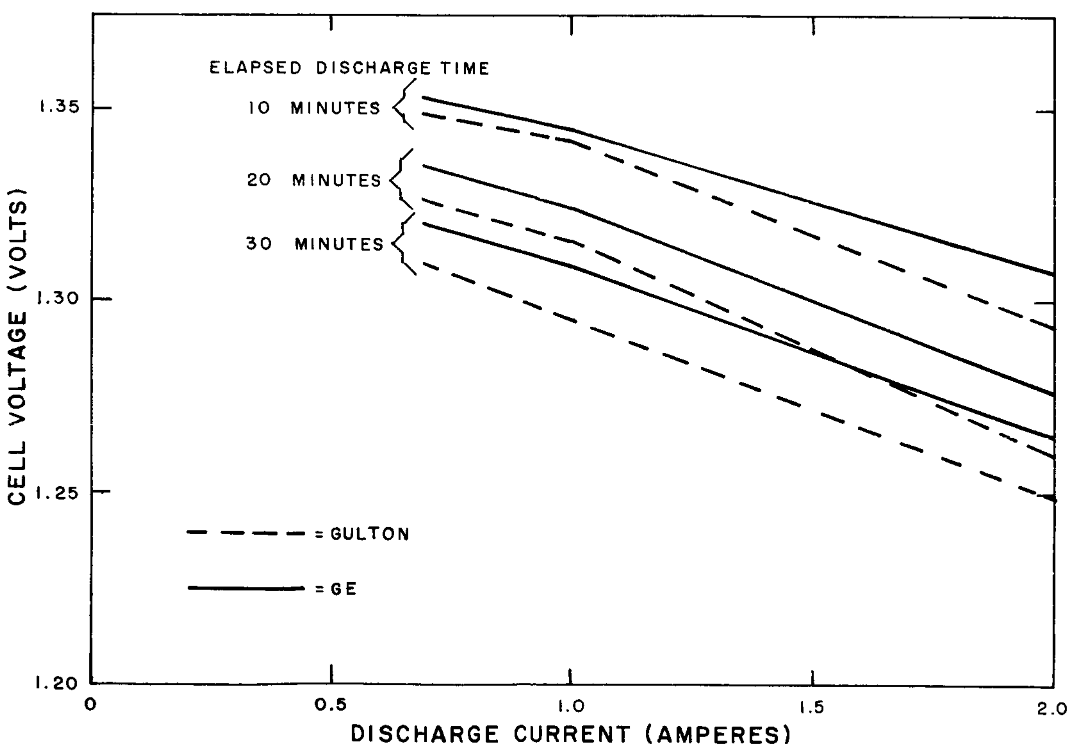


Figure 35. Comparison of General Electric and Gulton Cells — Cell Voltage Versus Discharge Current

TABLE 7. PRESSURE DATA

Group No. 1 (15° C)										
Event	Gulton No. 1	Gulton No. 2	G. E. No. 3	Gulton No. 4	Gulton No. 5	G. E. No. 6	G. E. No. 7	G. E. No. 8	G. E. No. 9	G. E. No. 10
Start 16-hour charge	-25	0	0	-20	-20	0	- 30	- 10	- 30	- 20
End 16-hour charge	-10	10	5	- 3	-10	5	0	- 5	- 30	- 15
Start Charge Test No.1	-20	5	0	-10	-10	0	0	0	- 30	- 15
End Charge Test No.1	0	10	5	8	4	4	17	0	- 25	22
Start Charge No. 11,12	-10	3	- 2	25	15	- 5	73	55	95	92
End Charge No. 11,12	28	25	8	60	55	5	113	70	112	133
End Final Charge	35	20	7	42	43	3	95	68	100	97
Final Reading (F.R.)	0	0	- 5	-20	0	- 5	50	50	80	38
F.R. + 5 hours	0	0	- 5	-20	0	- 5	46	45	75	35
F.R. + 55 hours	-10	- 5	-10	-20	-10	- 5	27	35	58	27
F.R. + 58 hours	-10	- 5	- 8	-20	-10	- 5	27	35	58	27
F.R. + 14 days	-20	0	-10	-20	-15	- 5	- 25	- 5	- 20	- 10
Group No. 2 (25° C)										
Event	Gulton No.1	Gulton No. 2	Gulton No. 3	Gulton No.4	Gulton No. 5	G. E. No. 6	G. E. No. 7	G. E. No.8	G. E. No. 9	G. E. No. 10
Start 16-hour charge	-20	-20	-30	-20	-30	0	- 25	- 20	- 15	- 25
End 16-hour charge	-10	0	0	-10	-20	0	- 10	- 10	- 10	- 20
Start Charge No. 1	-15	- 5	-15	-15	-20	0	- 15	- 20	- 15	- 20
End Charge No. 1	- 5	16	5	5	- 5	5	5	- 5	- 10	- 10
Start Charge No. 11,12	-10	25	3	7	- 3	40	48	53	25	20
End Charge No. 11,12	15	97	72	72	43	102	133	134	40	57

NOTE: Readings denoted with a "minus" sign are in inches of mercury; readings without the sign are in pounds per square inch gauge.

TABLE 7. PRESSURE DATA (Continued)

Group No. 2 (25° C) (Continued)										
Event	Gulton No. 1	Gulton No. 2	Gulton No. 3	Gulton No. 4	Gulton No. 5	G. E. No. 6	G. E. No. 7	G. E. No. 8	G. E. No. 9	G. E. No. 10
End Final Charge	- 2	16	10	10	4	30	28	33	26	20
Final Reading (F.R.)	-20	-20	-25	-15	-25	15	8	15	20	12
F.R. + 23 hours	-20	-20	-25	-15	-25	15	8	15	20	12
F.R. + 55 hours	-20	-20	-30	-15	-30	8	- 5	- 5	10	0
F.R. + 58 hours	-20	-20	-30	-15	-30	8	- 5	- 5	10	0
F.R. + 14 days	-20	-20	-25	-15	-30	0	- 25	-25	-15	-25
Group No. 3 (35° C)										
	Gulton No. 1	Gulton No. 2	G. E. No. 3	Gulton No. 4	Gulton No. 5	G. E. No. 6	G. E. No. 7	G. E. No. 8	G. E. No. 9	G. E. No. 10
Start 16-hour charge	-30	-30	-30	-10	-25	-25	-30	0	0	-25
End 16-hour charge	0	-10	-30	5	-10	0	-15	5	5	-10
Start charge No. 1	-20	-20	-30	0	-20	-15	-25	0	5	-20
End charge No. 1	5	-10	-30	5	-10	0	-10	0	5	-10
Start charge No. 11, 12	7	-15	- 5	10	-15	- 5	-10	7	7	-15
End charge No. 11, 12	65	10	40	65	10	58	37	60	24	37
End final charge	10	-10	- 5	15	- 5	5	0	12	10	- 5
Final Reading (F.R.)	-25	-20	-10	- 5	-25	-18	-18	5	8	-20
F.R. + 3 hours	-25	-23	-18	-10	-25	-20	-20	3	5	-25
F.R. + 55 hours	-30	-23	-15	-10	-25	-20	-30	-10	0	-30
F.R. + 58 hours	-30	-25	-15	-10	-25	-20	-30	-10	0	-30
F.R. + 14 days	-30	-20	-25	-10	-25	-20	-30	-10	0	-30

NOTE: Readings denoted with a "minus" sign are in inches of mercury; readings without the sign are in pounds per square inch gauge.

TABLE 7. PRESSURE DATA (Continued)

Group No. 4 (45° C)											
Event	Gulton No. 1	Gulton No. 2	Gulton No. 3	G. E. No. 4	Gulton No. 5	Gulton No. 6	G. E. No. 7	G. E. No. 8	G. E. No. 9	G. E. No. 10	G. E. No. 11
Start 16-hour charge	-30	-15	-15	0	0	-15	-20	0	5	-20	-25
End 16-hour charge	-15	5	10	13	15	0	0	0	10	10	-10
Start charge No. 1	-25	-10	- 5	8	8	-10	-20	3	8	-10	-20
End charge No. 1	-20	0	5	13	20	- 5	0	5	10	5	-15
Start charge No. 11, 12	-25	- 5	- 2	8	8	-12	-17	3	5	- 5	-20
End charge No. 11, 12	0	21	38	29	47	14	28	13	14	57	11
End final charge	-10	10	17	20	18	5	12	8	10	15	0
Final Reading (F.R.)	-25	-15	-15	5	0	-15	-20	0	5	-25	-25
F.R. + 2 hours	-30	-15	-15	5	0	-18	-20	0	5	-20	-22
F.R. + 55 hours	-30	-15	-15	5	0	-18	-20	0	5	-25	-22
F.R. +58 hours	-30	-15	-15	5	0	-15	-20	0	5	-25	-22
F.R. +14 days	-30	-15	-15	0	0	-18	-20	0	0	-30	-30

NOTE: Readings denoted with a "minus" sign are in inches of mercury; readings without the sign are in pounds per square inch gauge.

5. Computer Input

The prime objective of this study was to provide input data for the computer program. These data are summarized in Table 8. The data, which define the performance characteristics of the cells, are arranged in four groups, representing cell temperatures of 15, 25, 35 and 45° C, respectively.

There are ten columns of data in the table. The first column specifies the load or charge current parameter. Thus, lines 1, 2, and 3 represent discharge currents of 2.0, 1.0 and 0.69 amperes, respectively. The fourth line represents a no-load or open circuit condition. Lines 5, 6, 7, and 8 represent charging currents of 0.40, 0.80, 1.00, and 1.20 amperes respectively.

Columns 2 through 10 give the cell terminal voltages which correspond to the load or charge current of the first column at various states of charge of the cell. The states of charge are 60, 80, 85.1, 88.8, 96.2, 100, 102, 108, and 140 percent. The full charge data is presented in Column 7 for all four temperatures. As shown in Figure 30, the actual cell capacity is a function of temperature. However, a constant capacity of 270 ampere-minutes has been assumed in order to be compatible with the computer program.

D. WEIGHT ANALYSIS

The updated weight analysis for the storage module is presented in Table 9. The new analysis is based on actual engineering model hardware.

E. STORAGE MODULE VIBRATION TEST

1. General

During this reporting period, the engineering model of the storage module was subjected to prototype-level vibration testing. The objectives of the test were as follows:

- To determine how component design changes have affected critical stress regions in the module housing; and
- To verify the final design of the storage module with respect to increased low-frequency thrust vibration levels.

The prototype level vibration testing of the storage module was performed on July 22 and 25, 1966 using the AED MB C-210, 25,000 pound force exciter. Accelerometers and strain gages were mounted on the module and on the test fixture as shown in Figures 36 through 43.

TABLE 8. TEST DATA SUMMARY

	Current (amperes)	Cell Voltages for Various States of Charge								
		60%	80%	85.1%	88.8%	96.2%	100%	102%	108%	140%
Group No. 1 (15° C)	-2.0	1.234	1.251	1.263	1.289	1.359	1.410			
	-1.0	---	1.270	1.285	1.302	1.356	1.422			
	-0.69	1.255	1.282	1.290	1.300	1.343	1.391			
	0.0	1.267	1.294	1.316	1.329	1.376	1.420			
	0.4	---	1.321	1.370	1.392	1.450	1.482	1.493	1.505	1.515
	0.8	---	1.312	1.370	1.405	1.481	1.518	1.536	1.540	1.540
	1.0	---	1.321	1.355	1.382	1.442	1.473	1.495	1.550	1.550
	1.2	---	1.323	1.378	1.412	1.478	1.517	1.530	1.565	1.565
Group No. 2 (25° C)	-2.0	1.238	1.255	1.265	1.282	1.391	1.381			
	-1.0	---	1.273	1.282	1.294	1.339	1.400			
	-0.69	1.252	1.282	1.290	1.300	1.330	1.367			
	0.0	1.265	1.295	1.315	1.330	1.362	1.395			
	0.4	---	1.320	1.362	1.386	1.422	1.446	1.455	1.460	1.460
	0.8	---	1.310	1.365	1.390	1.440	1.470	1.479	1.479	1.479
	1.0	---	1.313	1.363	1.388	1.432	1.458	1.475	1.485	1.485
	1.2	---	1.316	1.368	1.392	1.441	1.465	1.479	1.490	1.490
Group No. 3 (35° C)	-2.0	1.232	1.256	1.265	1.280	1.318	1.343			
	-1.0	---	1.279	1.287	1.295	1.322	1.360			
	-0.69	1.235	1.279	1.290	1.300	1.325	1.353			
	0.0	1.268	1.312	1.350	1.358	1.375	1.386			
	0.4	---	1.322	1.368	1.376	1.390	1.396	1.398	1.400	1.400
	0.8	---	1.315	1.356	1.372	1.398	1.407	1.410	1.415	1.415
	1.0	---	1.317	1.362	1.378	1.400	1.408	1.412	1.420	1.420
	1.2	---	1.318	1.367	1.382	1.408	1.418	1.424	1.435	1.435

TABLE 8. TEST DATA SUMMARY (Continued)

	Current (amperes)	Cell Voltages for Various States of Charge								
		60%	80%	85.1%	88.8%	96.2%	100%	102%	108%	140%
Group No. 4 (45° C)	-2.0	1.184	1.220	1.235	1.250	1.291	1.320			
	-1.0	---	1.249	1.259	1.270	1.300	1.335			
	-0.69	1.187	1.252	1.268	1.278	1.309	1.345			
	0.0	1.222	1.287	1.317	1.328	1.344	1.358			
	0.4	---	1.305	1.343	1.355	1.362	1.365	1.365	1.365	1.365
	0.8	---	1.287	1.335	1.352	1.375	1.378	1.378	1.378	1.378
	1.0	---	1.292	1.348	1.362	1.378	1.382	1.382	1.382	1.382
	1.2	---	1.293	1.348	1.365	1.386	1.389	1.390	1.390	1.390

TABLE 9. WEIGHT ANALYSIS - STORAGE MODULE

Assembly Name	RCA Drawing Number	Qty Per Equip	Estimated/Actual Weights (Pounds)			
			Est. 1-24-66	Est. 2-21-66	Est. 6-13-66	Actual 8-25-66
1. STORAGE MODULE ASSEMBLY						
A. Main Assembly	1759580 - 501		15.50	15.70	15.35	14.94
B. Weight of following items only; not picked up elsewhere: 32 nuts, 115 insulators, 70 screws, 19 washers, 4 clamps, 1 bracket, 6 screw locks, wire, lacing cord, solder, and potting			0.34	0.34	0.49	0.28
2. HEAT SINK WIRING ASSEMBLY	1849598 - 501	1	0.68	0.68	0.65	0.65
A. Second Level Assembly (See weight summary in item 14)						
B. Weight of following items only; not picked up elsewhere: wire, solder, and potting			0.01	0.01	0.01	0.01
3. ELECTRONICS BOARD CONFORMAL COATED	1849843 - 501	1	0.68	0.68	0.63	0.43
A. Second Level Assembly (See weight summary in item 13)						
B. Potting			0.01	0.01	0.01	0.01
4. MAIN HARNESS ASSEMBLY	1759579 - 501	1	0.73	0.73	0.77	0.77
A. Second Level Assembly (See weight summary in items 16 and 17)						

TABLE 9. WEIGHT ANALYSIS - STORAGE MODULE (Continued)

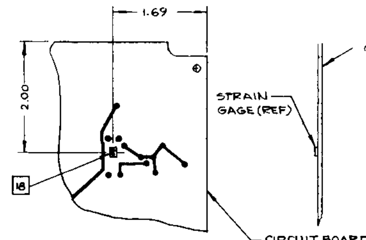
Assembly Name	RCA Drawing Number	Qty Per Equip	Estimated/Actual Weights (Pounds)			
			Est. 1-24-66	Est. 2-21-66	Est. 6-13-66	Actual 8-25-66
B. Weight of following items; not picked up elsewhere: tape and potting			0.20	0.20	0.20	0.20
5. RELAY & HARNESS BRACKET ASSEMBLY	1849822 - 501	1	0.49	0.69	0.23	0.23
A. Second Level Assembly (See weight summary item 18)						
B. Weight of following items only; not picked up elsewhere: 2 diodes, 1 relay, 4 nuts, 10 washers, 2 lugs, 1 bracket, 1 sleeve, wire, solder, and potting			0.10	0.10	0.09	0.09
6. BATTERY CELLS						
A. Cell Coated	1849 - 501	20	8.83	8.83	8.83	8.83
B. Cell with thermistor (1 cell, 1 bracket, 2 standoffs, 1 thermistor and potting)	1849819 - 501	2	0.88	0.88	0.89	0.89
C. Cell with thermistor	1849819 - 502	1	0.44	0.44	0.44	0.44
7. HOUSING MODULE COATED	184917 - 501	1	1.73	1.73	1.72	1.72
8. SEPARATOR CELL COATED	1849816 - 501	1	0.03	0.03	0.03	0.03
9. SIDE AND MOUNTING PLATE ASSEMBLY	1849830 - 501	1	0.52	0.52	0.52	0.52
A. Second Level Assembly (See weight summary in items 19 and 20)						
B. 12 Screws			0.03	0.03	0.02	0.02

TABLE 9. WEIGHT ANALYSIS - STORAGE MODULE (Continued)

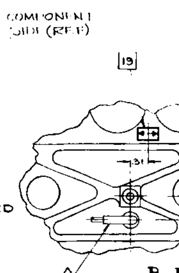
Assembly Name	RCA Drawing Number	Qty Per Equip	Estimated/Actual Weights (Pounds)			
			Est. 1-24-66	Est. 2-21-66	Est. 6-13-66	Actual 8-25-66
10. SPACER ROD ASSEMBLY	1700940 - 502	1	0.00	0.00	0.00	0.00
11. COVER MODULE ASSEMBLY	1849815 - 501	1	0.15	0.15	0.15	0.15
12. SPACER SUPPORT POST ASSEMBLY	1702666 - 501	1	0.00	0.00	0.00	0.00
13. STORAGE MODULE ELECTRONICS BOARD 9 capacitors, 30 diodes, 18 transistors, 1 board, 85 resistors, 27 terminals, 18 transipads, 5 mounting pads, wire, and solder.	1759578 - 501	1	0.67	0.67	0.42	0.42
14. HEAT SINK ASSEMBLY	1849596 - 501	1	0.83	0.83	0.64	0.64
A. Second Level Ass'y (See weight summary in item 17)						
B. Weight of items only; not picked up elsewhere: 10 screws, 10 nuts, 4 transistors, 8 resistors, 28 washers, 2 lugs, 1 buss wire ass'y, and tubing			0.42	0.42	0.32	0.32
15. BRACKET HEAT SINK 17 standoffs, 3 plugs, 14 inserts, and 1 bracket	1849558 - 501	1	0.41	0.41	0.32	0.32
16. HARNESS 25 PIN 1 connector, wire, sleeving, and solder	1759594 - 501	1	0.23	0.23	0.25	0.25

TABLE 9. WEIGHT ANALYSIS - STORAGE MODULE (Continued)

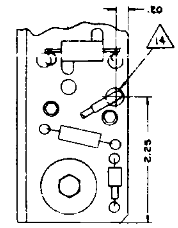
Assembly Name	RCA Drawing Number	Qty Per Equip	Estimated/Actual Weights (Pounds)			
			Est. 1-24-66	Est. 2-21-66	Est. 6-13-66	Actual 8-25-66
17. HARNES 9 and 37 PIN 2 connectors, wire, sleeving, and solder	1759595 - 501	1	0.30	0.30	0.32	0.32
18. BRACKET MOUNTING 1 bracket, 4 inserts, 2 studs, and 1 stand-off	1849821 - 501	1	0.13	0.13	0.14	0.14
19. SIDE PLATE 1 plate, 2 pads, 7 shims, and 7 rivets	1849837 - 501	1	0.24	0.24	0.24	0.24
20. MOUNTING PLATE 1 plate, 22 rivets, 11 nuts, and 8 inserts	1849810 - 501	1	0.25	0.25	0.26	0.26



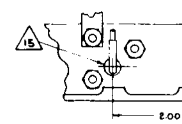
DETAIL OF BOARD SHOWING LOCATION OF STRAIN GAGE NOTE CORNER CUTOUT & COMPONENT SIDE



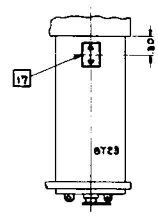
VIEW B-B



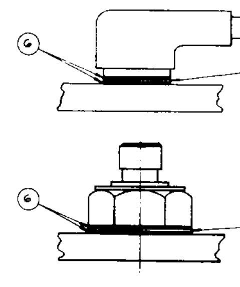
VIEW D-D



VIEW E-E



VIEW F-F



TYP ACCELEROMETER BONDING
SCALE: 4/1

TABLE I
ACCELEROMETER IDENTIFICATION

LOCATION △	ITEM NO.	SERIAL NO.
1	8	JA32
2	8	PF04
3	8	NC27
4	9	140
5	8	KD16
6	9	139
7	8	NC19
8	8	NC28
9	8	NC26
10	8	KD10
11	8	KC54
12	8	KC97
13	9	144
14	9	141
15	9	158

TABLE II
STRAIN GAGE IDENTIFICA

LOCATION □	ITEM NO.	S C
16	10	
17	10	
18	13	
19	10	
20	13	
21	10	
22	10	
23	10	
24	10	
25	10	

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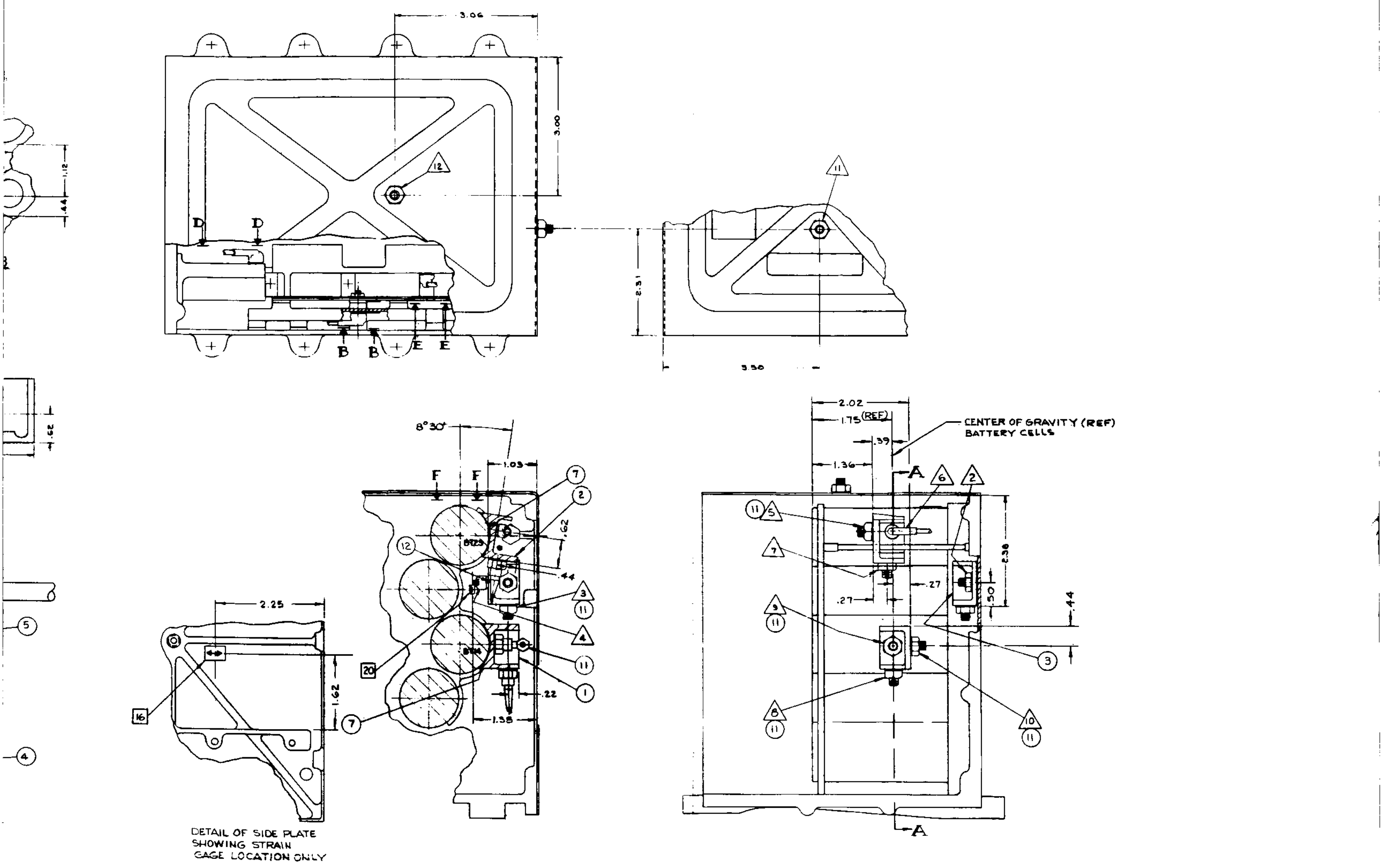

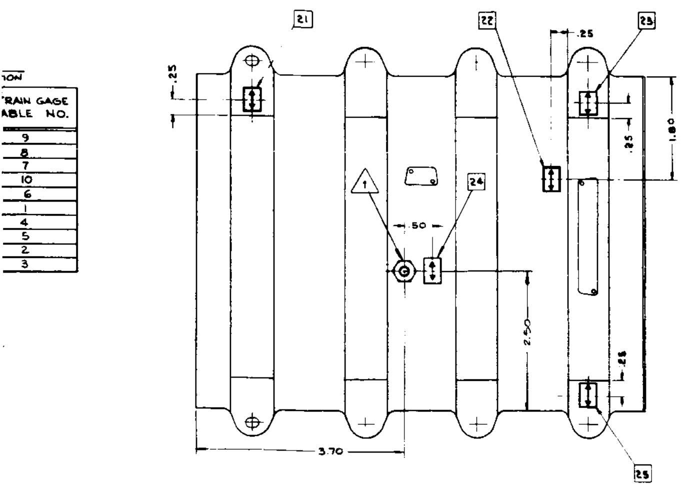

QTY -4	QTY -5	QTY -2	QTY -1	ITEM NO.	CODE IDENT	PART NO.	DESCRIPTION
			2	13		SEE NOTE 2	STRAIN GAGE
			4	12		ENDEVCO	CONNECTOR, STRAIGHT
			5	11		ENDEVCO	CONNECTOR, RIGHT ANGLE
			8	10		SEE NOTE 2	STRAIN GAGE
			5	9		2ES (CLEVITE)	ACCELEROMETER (CLEVITE)
			11	8		2226 (ENDEVCO)	ACCELEROMETER (ENDEVCO)
			AR	7		SEE NOTE 1	DENTAL CEMENT
			AR	6		910 (ADHESIVE)	ADHESIVE, EASTMAN
			5	5		SK1764238-1	INSUL. PAD
			11	4		SK1764238-2	INSUL. PAD
			1	3		SK1843713-3	BRACKET, ACCELEROMETER
			1	2		SK1843713-2	BRACKET, ACCELEROMETER
			1	1		SK1843713-1	BRACKET, ACCELEROMETER

LIST OF MATERIALS

Figure 36. Accelerometer and Strain Gauge Locations on Storage Module

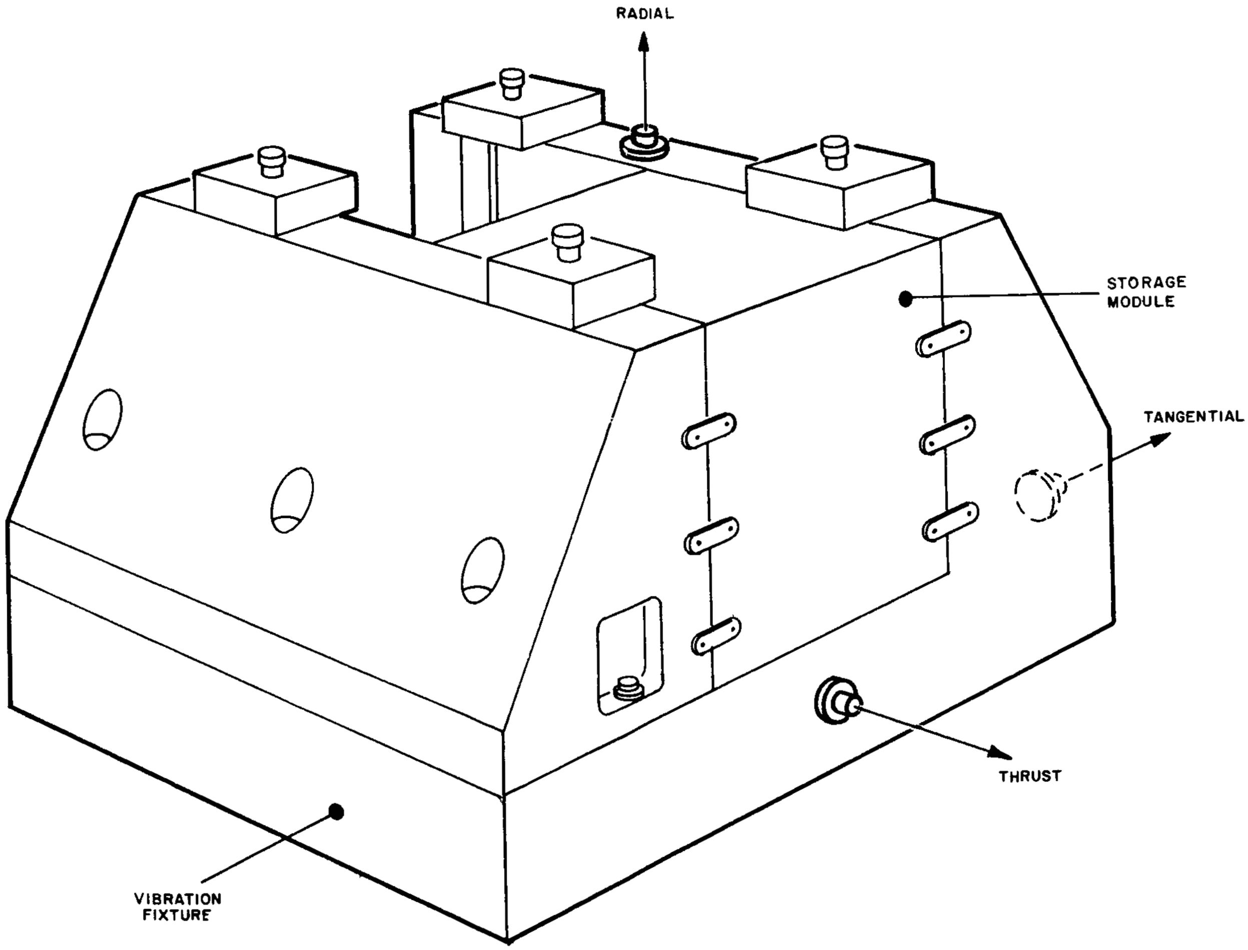

Figure 37. Location of Accelerometers on Vibration Fixture

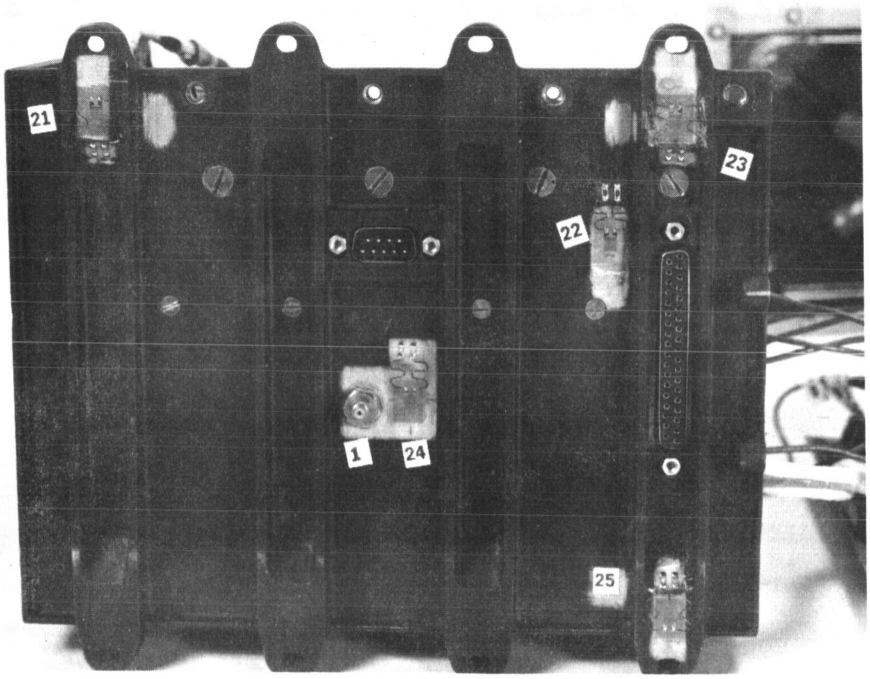

Figure 38. Location of Instrumentation on Bottom of Storage Module

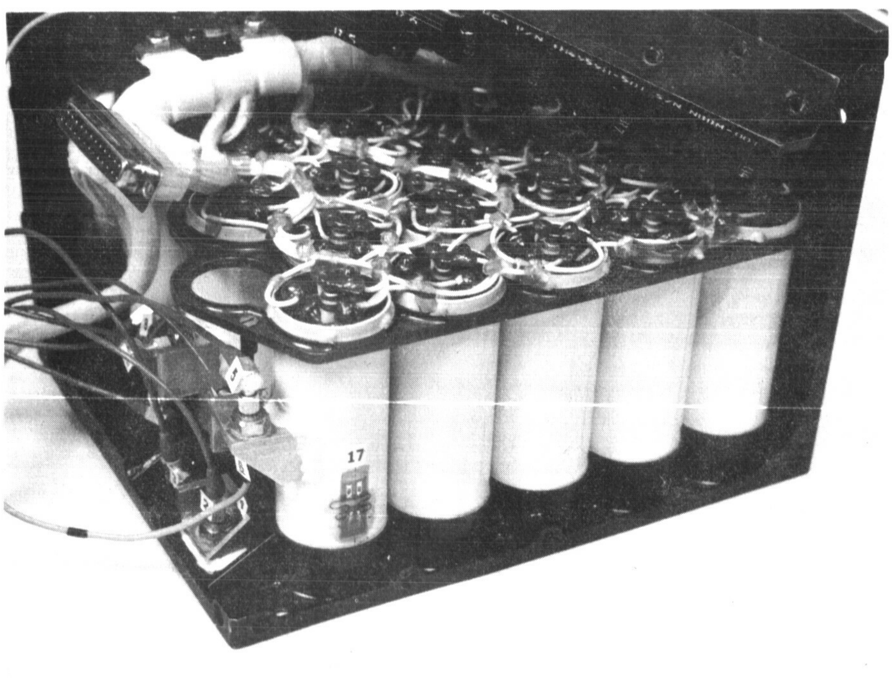

Figure 39. Location of Instrumentation on Storage Cells

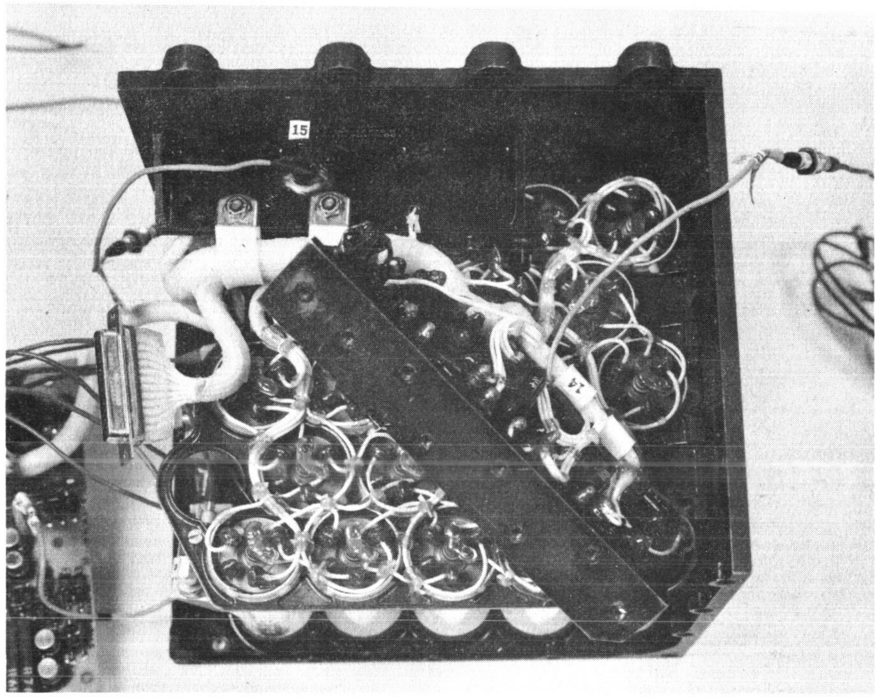

Figure 40. Location of Instrumentation on Relay Bracket

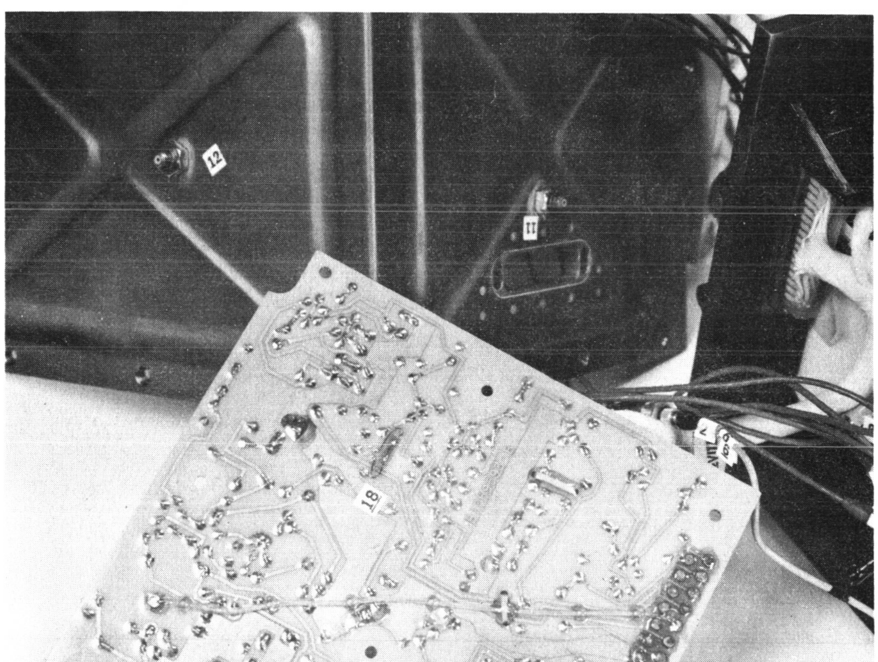

Figure 41. Location of Instrumentation on Circuit Board and Cover Panel

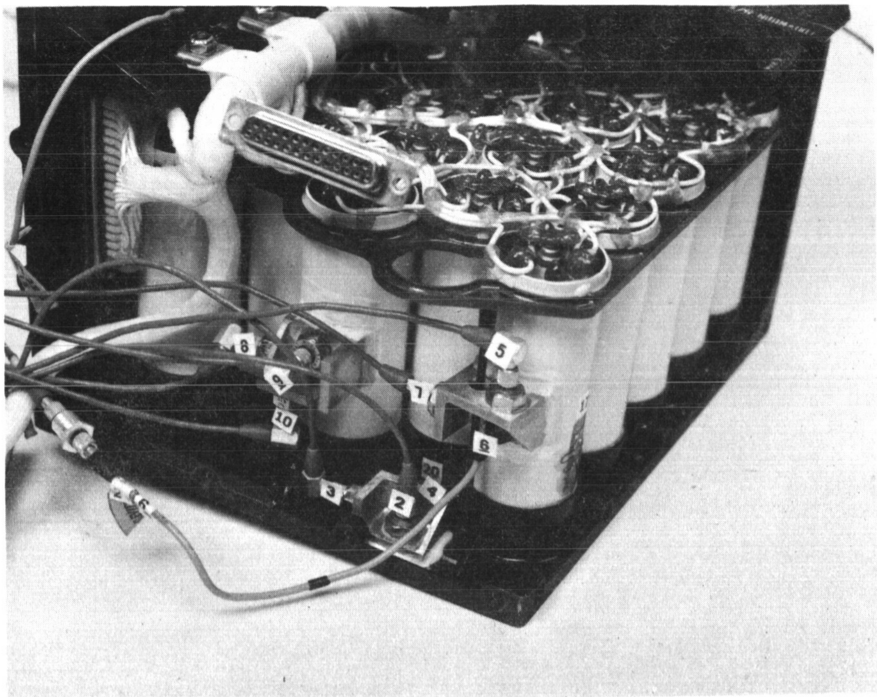

Figure 42. Close-Up View of Instrumentation on Battery Cells and Module Side

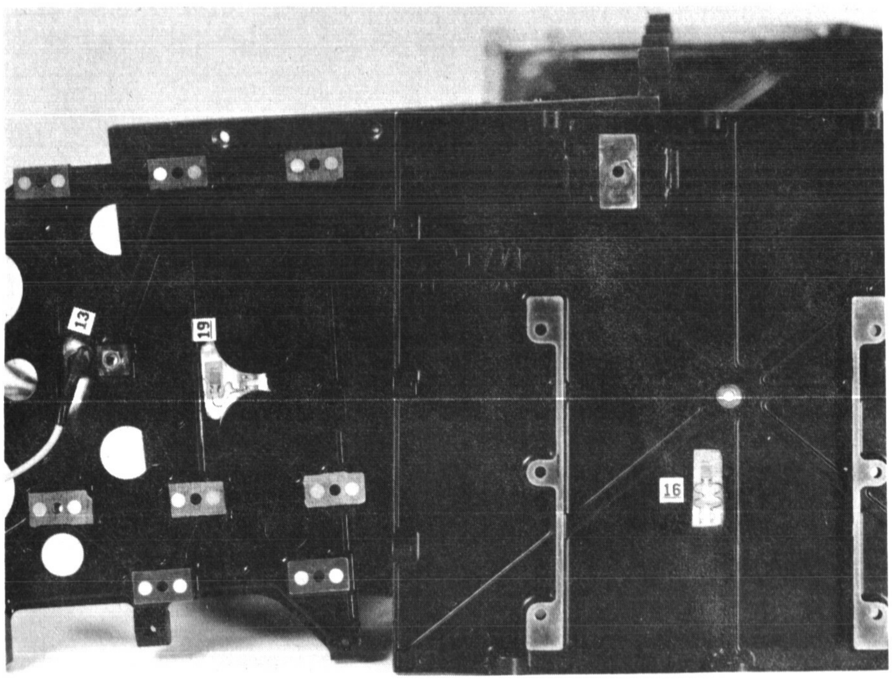

Figure 43. Location of Instrumentation on Side Panel and Circuit Board Mounting Plate

The testing consisted of a low-level sine survey, a prototype level sine run, and a random vibration run along each of three orthogonal axes (thrust, tangential, and radial). The vibration levels are presented in Table 10 and the respective directions of excitation are indicated in Figure 36.

The module was subjected to vibration along the thrust axis for runs No. 1, 2, and 3. Runs No. 4, 5, and 6 were performed along the tangential axis, and runs No. 7, 8, 9, and 10 were performed along the radial axis. Run No. 10 was a re-run of the radial direction sine sweep (run No. 8); the re-run was necessary because the strain gage circuits were not activated during run No. 8.

Table 11 presents a summary of thc data in tabulated form, showing peak responses, the peak response frequencies, and transmissibilities for each transducer location.

2. Test Results

a. THRUST-AXIS EXCITATION

The highest response obtained within the module during the thrust-axis vibration was 58G, which was obtained on Battery Cell No. 23. This value was measured along the axis of excitation at a frequency of 630 cps. The maximum cross-talk value obtained was 46G, which was measured along the tangential axis on Battery Cell No. 23. The cross-talk measurement was obtained at a frequency of 440 cps. Measurements of 130G and 56G at 195 cps were obtained on the sheet-metal cover plate, but these readings do not affect the module or any components within the module and were expected due to the nature of the cover-plate construction.

b. TANGENTIAL-AXIS EXCITATION

The highest response obtained within the module during tangential-axis vibration was 48G, which was measured along the thrust axis of Battery Cell No. 23 at a frequency of 660 cps. The highest response measured in the direction of excitation was 43G, which was measured on Battery Cell No. 23 at a frequency of 270 cps.

c. RADIAL-AXIS EXCITATION

The highest response obtained within the module during radial-axis vibration was 66G, which was measured along the tangential axis of the Heat Sink at a frequency of 950 cps. The highest response measured in the direction of excitation was 42G, which was measured on Battery Cell No. 23 at a frequency of 520 cps.

TABLE 10. VIBRATION LEVELS

Sine		
Frequency (cps)	Thrust Axis (G, 0 to peak)	Transverse Axes (G, 0 to peak)
5 to 200	15	10
200 to 2000	10	10
Sweep Rate: 1 octave per minute Displacement limited to 0.5 inch double amplitude		
Random		
Frequency Bandwidth:	20 to 2000 cps	
Spectral Density:	0.2 g^2/cps	
Overall Level:	20 g RMS	
Duration:	4 minutes/axis	

d. MAXIMUM "Q"

The maximum "Q" obtained for any test axis was 6.6, which was obtained along the tangential axis of the heat sink during radial-axis vibration.

3. Conclusions

The peak thrust response of 58G, as measured on accelerometer 7, occurred at 630 cps. Data obtained from the accelerometer mounted on the relay bracket show a maximum tangential response axis level of 27G at a frequency of 920 cps. This level is within the qualification value specified by the manufacturer of the relay (Babcock BR-20, RCA Part No. 1721945) located on this bracket. Values of excitation in thrust and radial axes were not measured.

The effect of the increased sine qualification level from 10 to 15G between 5 and 200 cps is minimal, since storage module resonant frequencies are primarily above 200 cps.

The results of this test confirm the adequacy of the design as predicted by the previous vibration analysis. No problems were encountered.

TABLE 11. STORAGE MODULE VIBRATION TEST SUMMARY

Transducer		Location[1]	Mounting Direction	Thrust-Axis Excitation			Tangential-Axis Excitation			Radial-Axis Excitation		
				Peak Response	Peak Response Frequency	Transmis-sibility	Peak Response	Peak Response Frequency	Transmis-sibility	Peak Response	Peak Response Frequency	Transmis-sibility
Accelerometer	1	Bottom of Module at Center	Thrust Axis	20G	440 cps	2.0	14G	300 cps	1.4	8G	620 cps	-
	2	Bracket on Right Side of Module	Tangential Axis	30G	440	3.0	32G	270	3.2	16G	760	1.6
	3		Thrust Axis	21G	650	2.1	17G	1700	1.7	5.8G	1700	-
	4		Radial Axis	8.8G	450	-	16G	1800	1.6	19G	750	1.9
	5	Bracket on Cell No. 23	Tangential Axis	46G	440	4.6	43G	270	4.3	33G	700	3.3
	6		Radial Axis	32G	650	3.2	11G	270	1.1	42G	520	4.2
	7		Thrust Axis	58G	630	5.8	48G	660	4.8	38G	620	3.8
	8	Bracket on Cell No. 14	Thrust Axis	34G	650	3.4	15G	300	1.5	11G	550	1.1
	9		Radial Axis	11G	700	1.1	N.D.[4]	N.D.[4]	N.D.[4]	20G	640	2.0
	10		Tangential Axis	43G	630	4.3	30G	275	3.0	27G	520	2.7
	11	Side of Cover Plate	Radial Axis	56G	195	5.6	33G	275	3.3	55G	220	5.5
	12	Top of Cover Plate	Thrust Axis	130G	195	13.0	60G	275	6.0	84G	200	8.4
	13	Circuit Board Mounting Plate	Tangential Axis	28G	1500	2.8	40G	275	4.0	19G	1500	1.9
	14	Side of Heat Sink	Tangential Axis	28G	440	2.8	30G	270	3.0	66G	950	6.6
	15	Side of Relay Bracket	Tangential Axis	27G	920	2.7	19G	870	1.9	9.5G	1220	-
Strain Gauge	1	Side Plate	Thrust Axis	(2)	(2)	-	50 μ in./in.	275	-	N.D.[4]	N.D.[4]	
	2	Side of Cell No. 23	Tangential Axis	21 μ in./in.	640	-	15 μ in./in.	650	-	15 μ in./in.	1100 cps	
	3	Circuit Board	Thrust Axis	29 μ in./in.	640	-	35 μ in./in.	275	-	(6)	(6)	
	4	Circuit Board Mounting Plate	Radial Axis	29 μ in./in.	630	-	23 μ in./in.	275	-	19 μ in./in.	1100	
	5	Right Side of Module	Thrust Axis	35 μ in./in.	440	-	25 μ in./in.	290	-	18 μ in./in.	1250	
	6	Bottom-Corner of Module	Tangential Axis	34 μ in./in.	450	-	32 μ in./in.	280	-	20 μ in./in.	530	
	7	Bottom-Off Module Corner	Tangential Axis	16 μ in./in.	1300	-	22 μ in./in.	280	-	19 μ on./in.	1200	
	8	Bottom-Corner of Module	Tangential Axis	36 μ in./in.	440	-	29 μ in./in.	280	-	(6)	(6)	
	9	Bottom-Center of Module	Tangential Axis	(2)	(3)	-	(5)	(5)	-	(5)	(5)	
	10	Bottom-Corner of Module	Tangential Axis	N.D.[4]	N.D.[4]	-	N.D.[4]	N.D.[4]	-	(7)	(7)	

Notes:
(1) See Figures 36 through 43
(2) Noise level at 40 μ in./in.; all responses below this level
(3) Noise level at 97 μ in./in.; all responses below this level
(4) No Data
(5) Noise level at 95 μ in./in.; all responses below this level
(6) Noise level at 25μ in./in.; all responses below this level
(7) Noise level at 3.2 μ in./in.; all responses below this level

F. MODIFICATION TO BATTERY DISCONNECT CIRCUIT

As a result of the design review of June 28-29, 1966, RCA was requested to determine the advisability of modifying the storage module design to enable disconnection of the battery tap circuit. An evaluation was conducted which indicated that this change should be made. The circuit design was subsequently changed in accordance with Modification No. 9 to the contract. The revised circuit is shown in Figure 44. The design has been reviewed from a reliability standpoint and has been incorporated in the engineering model storage modules.

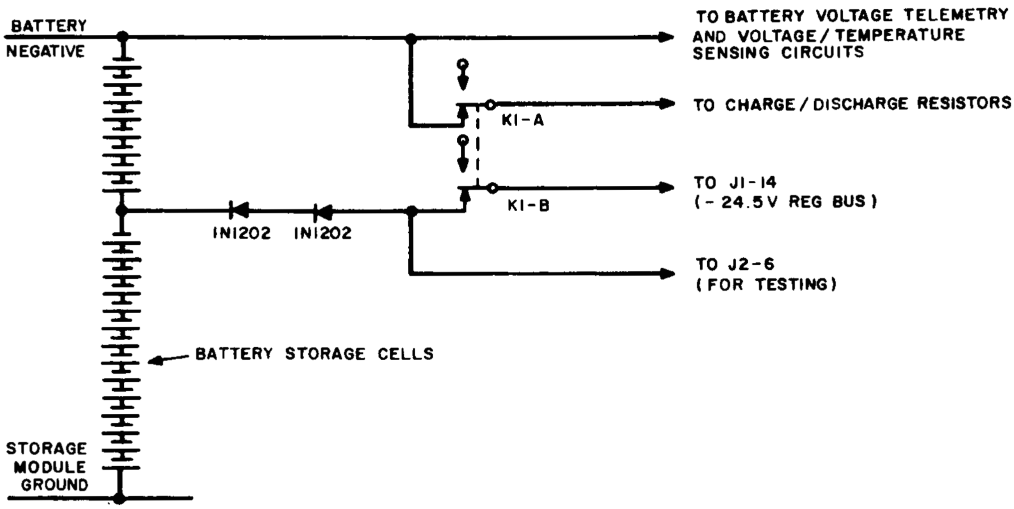

Figure 44. Modified Relay Circuit for Storage Module

SECTION IV

GROUND CHECKOUT EQUIPMENT AND TEST DOCUMENTATION

A. GROUND CHECKOUT EQUIPMENT

1. Module Test Units

Two module test units (EM-1 and -2), one of which is shown in Figure 45, were completed during this period. One unit was used successfully to test the following circuits or functions of a storage module:

(1) Charge control circuit,

(2) High temperature circuit,

(3) Voltage temperature circuit,

(4) Trickle-charge override circuit,

(5) Tap diode,

(6) Relay disconnect circuit,

(7) Charge current telemetry,

(8) Discharge current telemetry,

(9) Battery voltage telemetry, and

(10) Temperature telemetry circuit.

The module test unit will be used to test a control module during the next quarterly period.

2. Subsystem Test Unit

Changes were made in the design of the battery current monitoring circuits of the subsystem test unit. Magnetic current sensors will be used to monitor total battery current as well as current from each of the eight storage modules.

Fabrication and assembly of the subsystem test unit was started during this period and completion is expected during the next period.

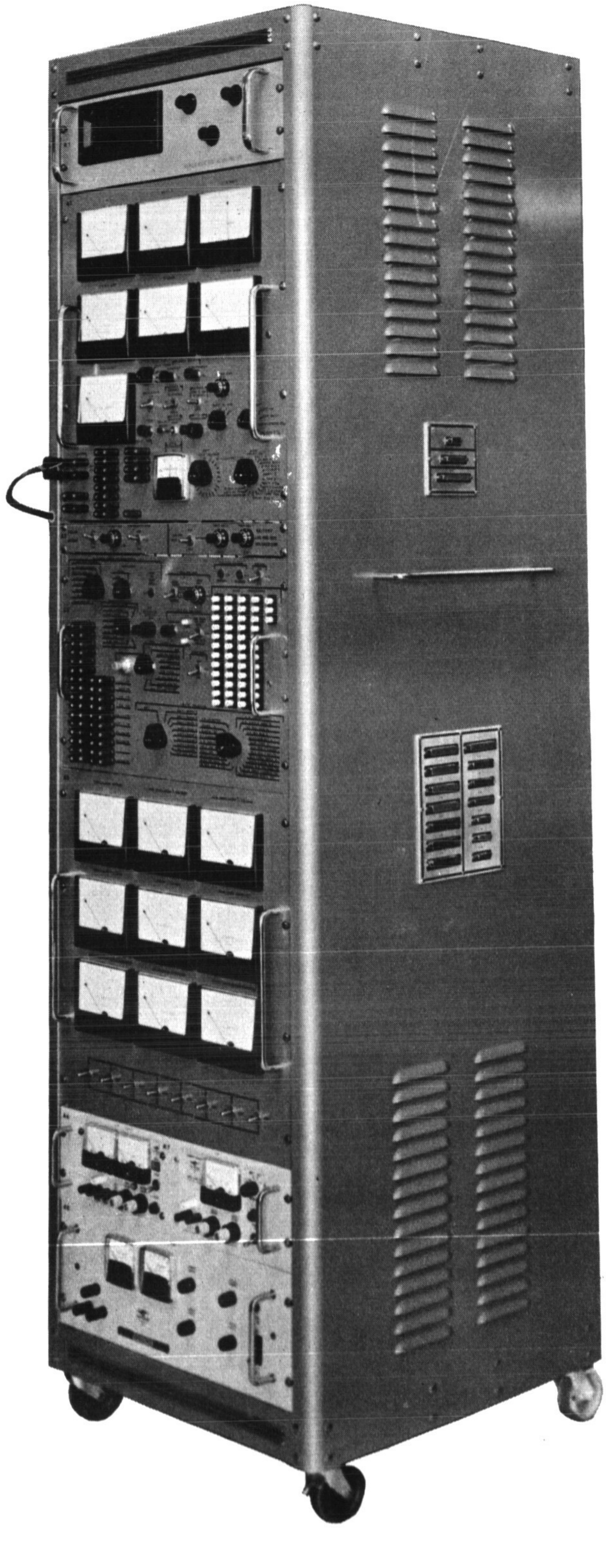

Figure 45. Module Test Unit

B. TEST DOCUMENTATION

Test procedures for the Engineering Models were prepared and evaluated during tests performed on the Engineering Models (EM-1) of the storage module and the control module. Changes required as a result of the tests are being incorporated into the procedures.

Test procedures for the prototype models were prepared and bench tests and vibration tests were performed on the storage module in accordance with the procedure.

SECTION V
ENGINEERING RELIABILITY

A. GENERAL STATUS

Engineering Reliability activity during this quarterly period consisted mainly of the inclusion of the Contract Modification No. 3 (Mod 3) changes into the Parts Application Study and into the Failure Mode Effect and Criticality Analysis.

All non-standard parts have been reviewed and all data have been submitted to NASA. NASA has approved the use of all proposed non-standard parts.

Engineering Reliability personnel attended the major design review at GSFC in June and made a detailed presentation of the Parts Application, Stress Analysis, Reliability Prediction, and Failure Mode Effect and Criticality Analysis.

A Parts Application Review Report for Mod-3 has been submitted to NASA. A detailed Failure Mode Effect and Criticality Analysis Report will be submitted to NASA during the next period.

B. PARTS PROGRAM AND RELIABILITY ANALYSIS

1. Introduction

The parts program and reliability analysis effort consists of three major tasks: Parts Selection and Control; Parts Application Review; and Reliability Predictions and Coordination.

Parts Selection and Control includes:

- Parts standardization,
- Parts derating policy
- Vendor surveys,
- Procurement document review,
- Purchase order review, and
- Parts preconditioning

Parts Application Review includes:

- Parts count;
- Non-standard parts review; and
- Preparation of parts work sheets, stress analyses and failure rate assignments.

Reliability predictions are based on an overall parts failure rate. where all part failures are considered to be equally critical and a function of part failure criticality. Reliability predictions are made for various combinations of surviving storage modules.

2. Parts Selection and Control

The basic elements of part selection and control were discussed in Quarterly Report No. 3, which included the standard and non-standard parts policy, derating, preconditioning, and vendor coordination.

3. Parts Application and Review

a. PARTS COUNT

The parts changes due to the Mod-3 effort have resulted in a slight change in complexity. A total of 1957 parts are used in the power subsystem, of which 328 are non-standard parts. A summary breakdown of standard and non-standard parts is presented in Table 12.

b. NON-STANDARD PARTS REVIEW

Non-standard parts for this program were parts not contained in the official Nimbus approved parts list, RCA Drawing No. 1846218, or in the Spacecraft Standards at the time of selection.

Approval for the use of non-standard parts is based on a non-standard parts data sheet request submitted by the Design Engineering group to Engineering Reliability. The subject form delineates a description and usage of the part, records of previous space program usage and application, reasons for not using a standard part, and other pertinent comments.

Engineering Reliability specialists review the submitted requirements and establish whether the respective parts can be reliably procured and whether test back-up data, or other pertinent data such as IDEP reports, vendor test data, Central Engineering records, etc., can be provided.

TABLE 12. QUANTITIES OF STANDARD AND NON-STANDARD PARTS

Component	Subassembly	Quantity of Parts	Quantity of Non-Standard Parts
Control Module	PWM Regulator (SK 1849871/1A)	233	54
	Bus Comparator (SK 1766551)	124	4
	Auxiliary Regulator (SK 1766557) (2 each)	60	0
	Current T/M (SK 1849871/2A	65	10
	Shunt Dissipator (SK 1766552)	21	0
	Bus Voltage T/M (SK 1766557)	18	0
	Miscellaneous Circuits	98	68
	Sub-Total	613	136
Storage Module (per Module)	Board A1	143	11
	Board A2 (Heat Sink)	13	7
	Board A3	3	0
	Board A4 (Battery Sensors)	3	3
	Shunt Dissipator	3	3
	Connectors	3	0
	Sub-Total, per module	168	24
	Sub-Total for eight storage modules	1344	192
Subsystem Total		1957	328

The various requirements have been coordinated on an individual basis with vendors. For example, for specially designed and custom-built transformers and reactors, special design review and plant inspection were carried out by the inductive component specialist.

Similarly, a special meeting with the technical representative of the vendor of the Genistron RFI filters was arranged to discuss design parts and test details.

A total of 35 specification control drawings for non-standard parts were generated and vendor coordination pursued.

c. FAILURE RATE ASSIGNMENTS

Failure rate assignments were made based on thermal and electrical part stress estimates furnished by the Thermal and Design Engineering groups, respectively. Stresses of a transient nature, or those having a short duty cycle, are noted where the absolute stress value may be misleading. An initial review of the parts application revealed several instances where parts exceeded the derating objectives. The Design Group was alerted to the stress conditions. Corrective steps, coordinated with Engineering Reliability, were taken to reduce the part application stress. A review of the final detailed Parts Work Sheets reveals no part being stressed beyond the values specified in the Nimbus Derating Policy.

4. Reliability Predictions

Reliability estimates were made for each of the components in the Nimbus-B power subsystem and for the overall, integrated power subsystem. The predictions for the subsystem were made for 3-, 6-, and 12-month mission durations, at two levels of part failure criticality, and for various combinations of survival of the eight, paralleled storage modules. (A storage module is comprised of a battery and battery electronics module.) The failure mode and effect analysis for the Nimbus-B power subsystem defines the failure criticality levels and takes into consideration the severity of single failure occurrences on mission performance.

The criticality categories are defined as follows:

(1) Failure Criticality No. 1 includes failures which are serious enough to cause loss of mission.

(2) Failure Criticality No. 2 includes failures which cause a significant degradation in mission performance or loss of one storage module.

(3) Failure Criticality No. 3 includes failures which are not capable of causing system degradation or loss of mission.

The failure rates for each of the subsystem components, exclusive of the solar array and battery are presented in Table 13.

TABLE 13. SUMMARY OF FAILURE RATES

Circuit or Box Identification	Failure Rates (Percent per 1000 hours)			
	Total Parts	Criticality Level 1	Criticality Level 2	Criticality Level 3
Auxiliary Regulator (2 ea) (P_{ar})	0.0702	-	0.0195	0.05070
Shunt Dissipator (P_{sd})	0.0701	-	0.0500	0.0201
Bus Comparator (P_{bc})	0.1484	0.0680	-	0.0804
PWM Regulator A (P_{RA})	0.1893	0.0001	-	0.1892
PWM Regulator B (P_{RB})	0.1893	0.0001	-	0.1892
Filters and Storage (P_F)	0.3919	0.2010	0.0320	0.1589
Miscellaneous Circuits (P_{MC})	1.1862	0.9610	0.0156	0.2096
Current Telemetry (P_{CTM})	0.4325	-	-	0.4325
Bus Voltage Telemetry (P_{VTM})	0.0568	-	-	0.0568
One Battery Electronics Module (P_{BEM}) (Exclus. of cells)	(0.7503)	-	-	-
Eight Battery Electronics Modules	6.0024	-	0.8272	5.1752
Total	8.7371	1.2302	0.9443	6.5626

Reliability predictions were made for the following subsystem operational events:

(1) Probability of success with no failure occurring in the subsystem (based on total parts count failure rate). This will yield a pessimistic mission reliability baseline. Component "worst case" reliability predictions are listed in Table 14.

(2) Probability that the subsystem will not experience a part or component failure of criticality level 1, for various combinations of surviving storage modules.

TABLE 14. SUMMARY OF "BASELINE" RELIABILITY PREDICTIONS FOR THE NIMBUS-B POWER SUBSYSTEM COMPONENTS, FOR TOTAL PARTS COUNT FAILURE RATE (CRITICALITY LEVELS 1 + 2 + 3)

Circuit or Box Identification	Probability of Survival		
	for 3 Months	for 6 Months	for 12 Months
One Battery Electronics Module (Exclus. of cells)	0.9835	0.9675	0.9364
Auxiliary Regulator (2 ea)	0.9985	0.9969	0.9938
Shunt Dissipator	0.9985	0.9969	0.9938
Bus Comparator	0.9968	0.9935	0.9869
PWM Regulator A	0.9960	0.9917	0.9833
PWM Regulator B	0.9960	0.9917	0.9833
Filters and Storage	0.9915	0.9828	0.9656
Miscellaneous Circuits*	0.9726	0.9490	0.9012
Current Telemetry	0.9862	0.9726	0.9460
Bus Voltage Telemetry	0.9988	0.9975	0.9950
Single Battery Pack.	0.9999	0.9999	0.9943
Solar Array (9 or less String Failures)	0.9999	0.9930	0.7560

* Miscellaneous circuits include fuse boards, solar array diodes, clock diodes, trickle charge overide circuit, battery diodes, and connectors.

The basic failure mode of a solar cell is open and is generally attributed to the opening of either one or both of the cell interconnections. Temperature cycling is considered to be the prime contributor to this failure mode. All other inter-module and panel connections or junctions have a relatively low failure rate as compared to the basic cell connections. Based on 4 million cell temperature cycles with one cell connection degradation experienced on the Nimbus solar cell qualification program, it was estimated that the Nimbus array has a cell failure rate of 250×10^{-9} failures per cell per temperature cycle (or orbit).

The cumulative probability of having not more than K string failures is presented, as a function of mission duration, in Table 15. The probability of survival of the solar array was based on the quantity of string losses not exceeding nine.

TABLE 15. PROBABILITY OF NOT MORE THAN K STRING FAILURES

K, Quantity of Failures	Probability (Percent)		
	for 3-month mission	for 6-month mission	for 12-month mission
0	2.8	0.1	0.0
1	14.7	0.9	0.0
2	31.5	4.4	0.0
3	57.5	13.9	0.2
4	77.7	31.2	1.1
5	89.1	53.6	4.3
6	98.4	74.8	12.8
7	99.7	89.3	29.3
8	99.9+	96.6	52.4
9	99.9+	99.3	75.6
10	99.9+	99.9	91.3
11	99.9+	99.9+	98.1
12	99.9+	99.9+	99.9
13	99.9+	99.9+	99.9+
14	99.9+	99.9+	99.9+

Each of the eight Nimbus-B storage modules consists of 23, series-connected, nickel-cadmium cells. The failure mechanism associated with batteries is one of "wear-out", which is normally distributed. Life expectancy of batteries can only be based on actual cycle life tests which are continuing (discussed in Quarterly Report No. 3 and in Section III of this report.) Battery failure is defined as an "end-of-discharge" voltage below 26.5 volts. The Crane cycling data is available at a 15-percent depth of discharge and at various battery test temperatures. In the Nimbus-B power supply application, a 15 percent depth of discharge is considered to be the "worst-case" condition for the 8-module configuration.

A summary of the reliability predictions is presented in Table 16.

TABLE 16. SUMMARY OF RELIABILITY PREDICTIONS

Assumed Mission Occurrences	Probability of Survival		
	for 3 Months	for 6 Months	for 12 Months
1. "Base Line" Prediction (Criticality Levels 1, 2, & 3)			
Nimbus B	0.820	0.670	
Nimbus C (F-6)*	0.680	0.460	
2. No Part Failure in Criticality Level 1, and 9 or Less Solar Array String Failures for:			
7 of 8 Storage Modules Surviving	0.968	0.916	0.608
6 of 8 Storage Modules Surviving	0.973	0.938	0.668
5 of 8 Storage Modules Surviving	0.973	0.940	0.677

* Nimbus C (F-6) has been flown. Its "baseline" reliability is shown for general comparison interest.

The reliability estimates are presented graphically, as a function of mission duration, in Figure 46.

5. Conclusions

Based on the parts stress and parts application reviews, all parts were found to be conservatively used and stressed within the Nimbus-B Power Supply Derating Policy.

No contractual numeric reliability requirement has been assigned to the power supply subsystem or its components. The reliability predictions made in this report are presented for information purposes and for possible inclusion in any overall spacecraft subsystem mission studies.

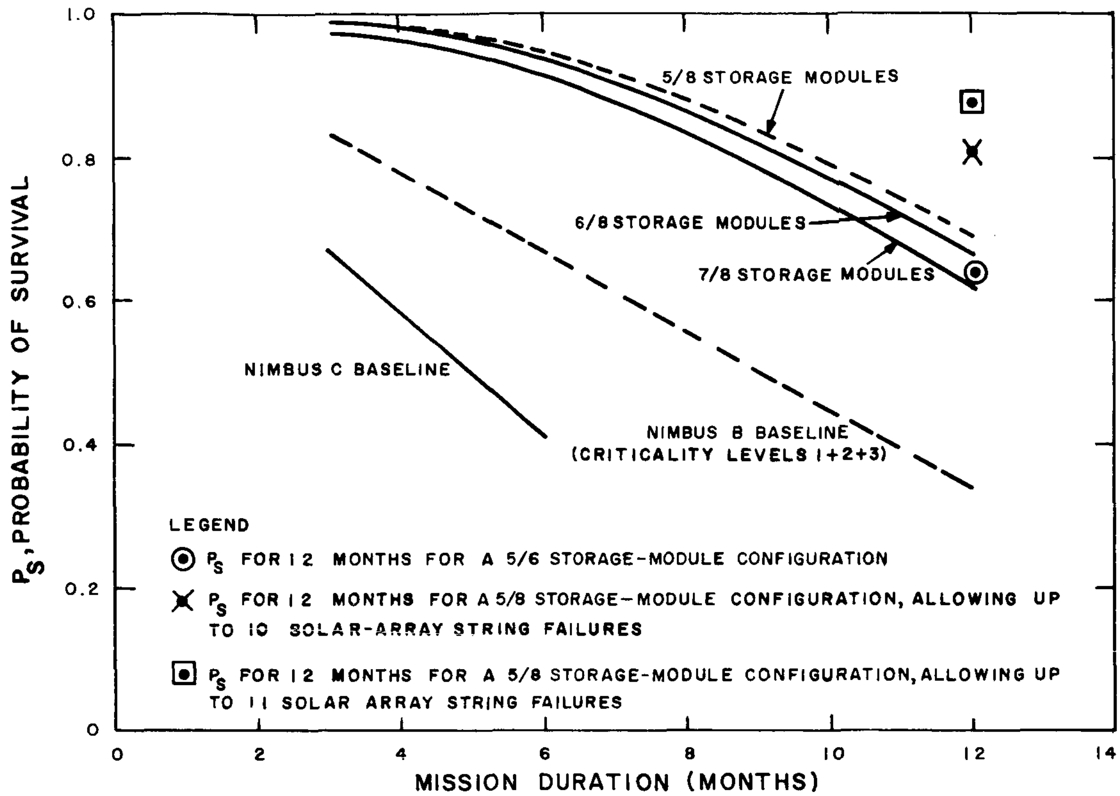

Figure 46. Probability of Survival as a Function of Mission Duration

C. FAILURE MODE EFFECT AND CRITICALITY ANALYSIS

1. Introduction

The updated analysis represents the latest design changes per Mod-3. The conclusion reached from the analysis is that the standby switching redundancy features designed into the power subsystem are capable of preventing almost all single catastrophic failures of a part or subsystem from causing loss of mission. All failures capable of causing a mission loss have been placed under additional control by the current limiting features and high current circuit protection inherent in the new Mod 3 design.

2. Failure Mode Categorization

There are 15 individual part failures that will cause a catastrophic system failure (Category No. 1).

There are 18 system or part failures that will cause system degradation or loss of a battery module (Category No. 2).

There are 54 system or part failures that can be rectified by stand-by redundancy switching and therefore cause no system degradation (Category No. 3).

A massive short circuit failure will cause the PWM regulator current limiting circuit to inhibit regulator bus comparator (RBC) switchover. It will also hold the PWM regulator output current to a level no greater than 20 amperes. A further reduction in output voltage will cause the two disconnect diodes to connect the fifteenth cell battery top (a high-current source) to the spacecraft bus. Any shorted or fused component connected to the spacecraft bus should blow free at this time since approximately 20 amperes is available for several hundred milliseconds. All system switching is automatic except for a manual ground command for trickle charge override, PWM regulator switchover backup, single or multiple battery module disconnect, and emergency disconnection of any shunt regulator dissipator arms whenever the need arises.

3. Method of Analysis

An engineering study of failure conditions and power system reaction is made in the following manner. Failures that may occur in the various parts of the power system are postulated by assumption of specific mode of failure. The reaction of the system to the assumed failures is analyzed. The results of all failure and effects analyses are then recorded on form AED-571. The following procedure is used to generate this analysis:

(1) The item or part group assumed to fail is identified.

(2) The failure mode is postulated.

(3) The causes of failure are determined and recorded.

(4) The symptoms and local effects, including dependent failures caused by the assumed failure, are developed from a study of the reaction of the system to the assumed failure.

(5) Existing compensatory provisions inherent in the system design are determined and entered on the form.

(6) The effect of the failure on a major category or mission success is recorded.

(7) The level of severity of the failure is noted:

Severity level 1: Mission failure
Severity level 2: Mission degradation, or loss of one storage module.
Severity level 3: No effect on mission

(8) The probability of failure occurrence is computed from failure rate data associated with the failed item part group, or part, and is recorded for each failure assumed.

(9) Special remarks and recommendations concerning the item or part are entered, if necessary.

4. Failure Summary for Nimbus-B Power Subsystem (Less Solar Array)

There are 15 separate part or item failures that fall in Category No. 1, which covers catastrophic failures.

There are 18 failures in Category No. 2, which covers mission degradation or loss of a battery module.

There are 54 failures in Category No. 3, which covers part failures that can be corrected by redundant switching. These failures do not cause operational degradation.

Items that may fail in Category No. 1 are the most important. Most of these items are located in the non-redundant energy storage network. In order to further reduce the impact of Category No. 1 items caused by catastrophic short circuit failures of single parts in the Energy Storage Network (ESN), a maximum current limiting circuit was designed to protect the PWM regulator by limiting the PWM regulator output current to approximately 20 amperes when a short appears across the spacecraft bus. An additional feature is provided in the event the bus voltage is reduced to less than 20 volts by this short. A disconnect diode is employed to automatically connect each storage module to a tap on the fifteenth cell. At this 20-volt level all eight storage modules are diode connected across the spacecraft load and the full battery capacity is available to blow free any shorted component that should withstand a current greater than 20 amperes.

Accordingly, the following parts could fail by shorting or opening and cause a Category No. 1 failure:

(1) ESN Filter inductors (serially open) L1, L2, RFI compartment.

(2) Shorted storage current inductor (shorted turns).

(3) Shorted energy storage diodes CR1, CR2, RFI Compartment, CR9, all boards.

(4) Shorted ESN filter capacitors (shunt caps) C1, C2, C3, C4 - RFI Compartment.

(5) Shorted solar-array filter capacitor C1, C2, C3, A13 board. RFI Compartment.

(6) 1-hertz clock pulse generator.

5. Results of Analysis

The failure rate of the entire Nimbus-B power subsystem, less the solar array and the RTG, is 8.737 percent per 1000 hours on a part count basis only. The total failure rate for parts failing in Category No. 1 is 1.2302 percent per 1000 hours or only 14.1 percent of the total parts count failure rate.

The total failure rate for parts failing in Category No. 2 is 0.9443 percent per 1000 hours or 10.2 percent of the total parts count failure rate.

The total failure rate for parts failing in Category No. 3 is 6.5626 percent per 1000 hours or 75.7 percent of the total parts count failure rate. (The 8.7371 percent per 1000 hours total failure rate includes all plugs, miscellaneous circuits, and all eight storage modules.)

The failure rates for the Mod 2 power subsystem are compared with those for the Mod 3 subsystem in Table 17. This comparison indicates the reliability growth attained when the latest design changes are incorporated. The large percentage of Category No. 3 failures demonstrates the capability of the Mod 3 power subsystem design to cope with single catastrophic component failures over a wide variety of operational conditions, since the inherent redundancy and short circuit protection of this design is capable of reducing the effect of these failures by automatic switchover backed up by ground commands.

TABLE 17. COMPARISON OF FAILURE RATES IN MOD 2 AND MOD 3 POWER SUBSYSTEMS

System	Failure Rate (percent)		
	Category No. 1	Category No. 2	Category No. 3
Mod 2	19.8	35.2	45.0
Mod 3	14.1	10.2	75.7

SECTION VI

PROGRAM FOR NEXT REPORTING PERIOD

A. GENERAL

This section enumerates the tasks scheduled for performance during the next quarter.

B. POWER SUBSYSTEM

At the power subsystem level, RCA plans to:

(1) Prepare the test procedures for the engineering model of the power subsystem (The procedures will cover bench performance testing, thermal-vacuum testing, and an end-to-end test.);

(2) Perform thermal-vacuum testing of the power subsystem in accordance with the Engineering Model Test Procedure;

(3) Perform an end-to-end test in sunlight, using a solar array assembly, a storage module and a control module;

(4) Review the test results and prepare a report on power subsystem performance;

(5) Update the energy-balance computer program on the basis of test results;

(6) Prepare a list of operational restraints to be observed during power subsystem testing and flight operation; and

(7) Revise the power subsystem performance specification in accordance with recent design changes and NASA review comments.

C. CONTROL MODULE

During the next quarter, Engineering Models 1 and 2 of the control module will be bench tested at three temperatures: -5°C, +25°C and +55°C. Engineering Model 1 will be subjected to vibration and electromagnetic interference tests.

Fabrication and pre-potting bench test of the prototype unit is scheduled for completion during this period.

D. STORAGE MODULE

The four groups of cells used in the parametric study reported herein will be subjected to a program of simulated orbiting cycling during the next quarter. Two test profiles will be employed during this program. Profile A will be the nominal system with the SNAP-19 RTG; Profile B will be the nominal system without the RTG. Upon completion of the simulated orbiting tests, further comparison of the General Electric and Gulton cells will be made based on the new data.

Assembly and individual testing of the eight engineering model storage modules is also scheduled for the next quarter.

Storage cells for the prototype storage modules have been received and are being tested. Performance of the cells will be reported in the next quarterly report.

E. ENGINEERING RELIABILITY

A separate report on the Failure Mode Effect and Criticality Analysis for the Nimbus-B Power Supply Subsystem will be issued during the next quarter.

The reliability predictions presented in Table 16 will be updated to include design changes up through Modification No. 3 to the contract.

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